

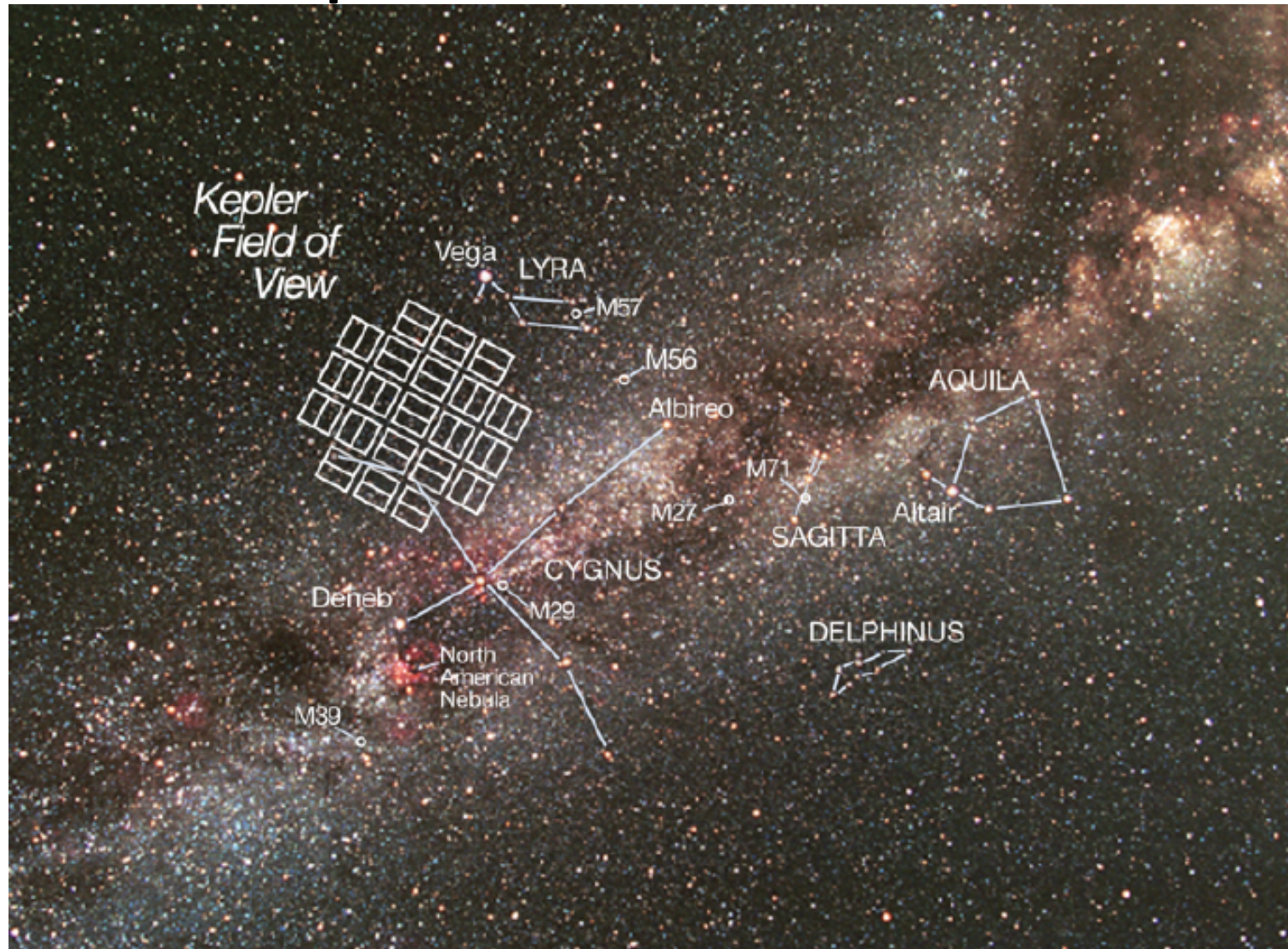


Steve B. Howell
NASA Ames Research Center

Outline

- Stellar Variability a la Kepler (Ciardi et al., 2011)
- Vetting (Small) ExoPlanets, Locally (Howell et al., 2011, Fressin et al., 2011)
- Other Solar Systems (Latham et al., 2011, Lissauer et al., 2011)
- Fun, New, Exciting Discoveries

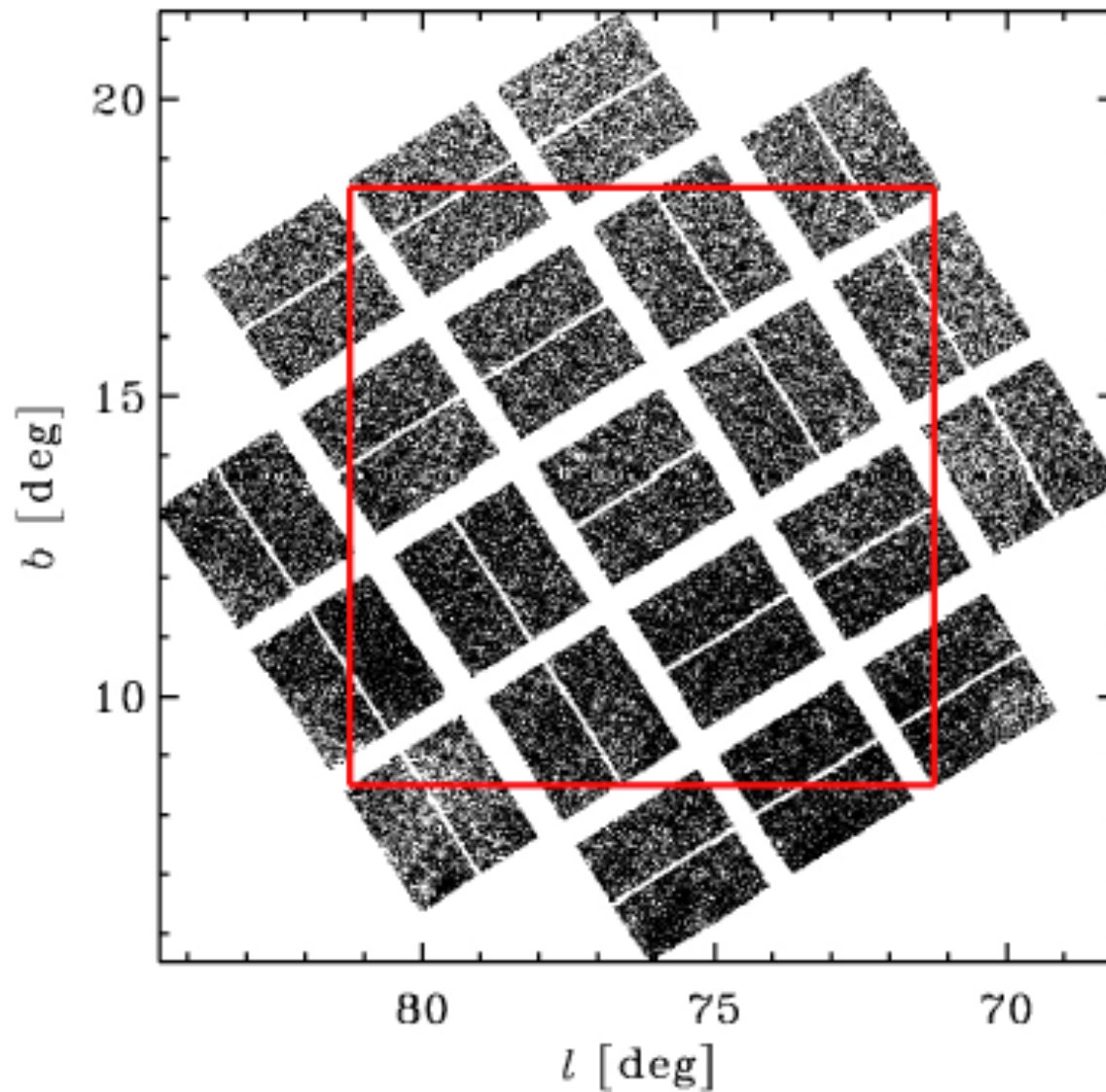
Kepler's Field of View



Stellar variability

- Take a sample of Kepler stars observed in the first month of operation
- Divide the sample into Dwarfs and Giants
- Examine the underlying variability of the light curves in this data set
- State the findings and discuss what it means for stars
- Ciardi et al. 2011 has details

Distribution of sample stars within Kepler FOV



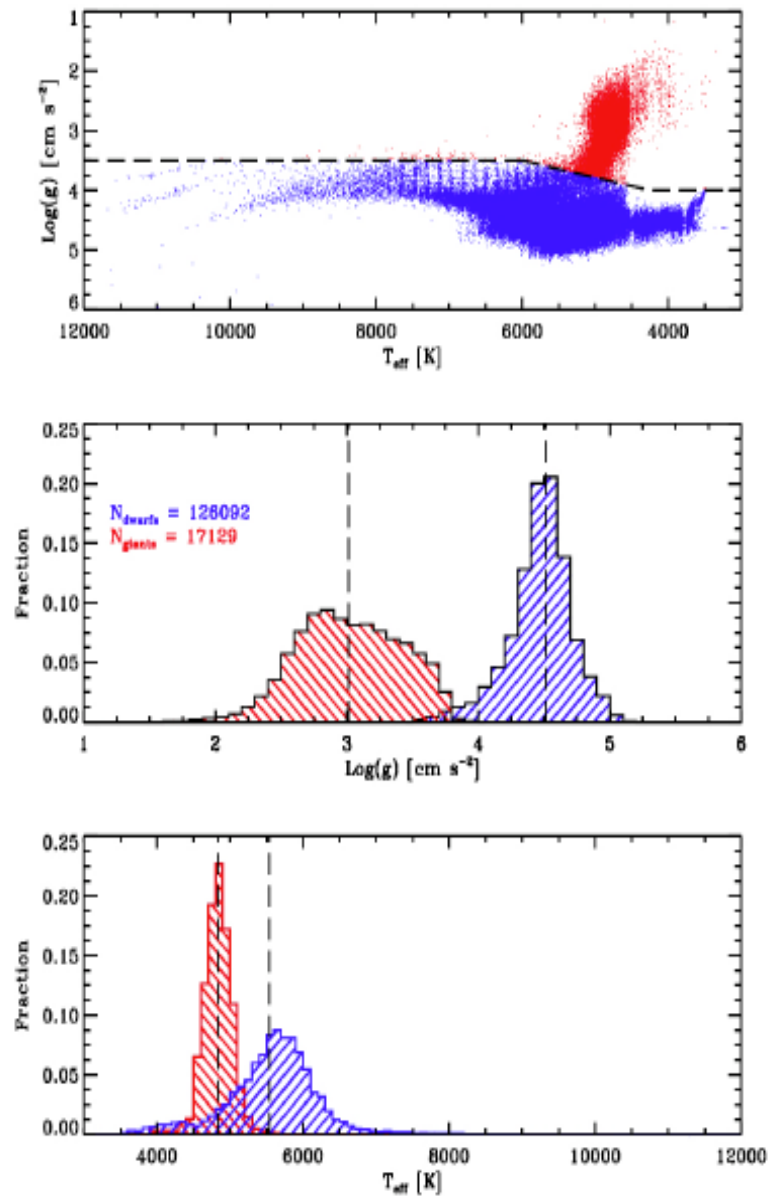
Light curves were 30
minute sampling and
33.5 days long

129,000 Dwarfs

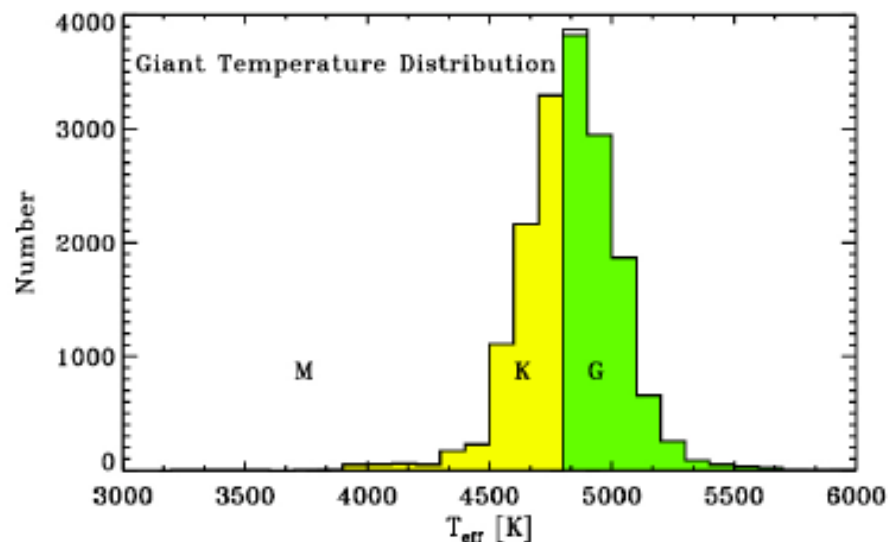
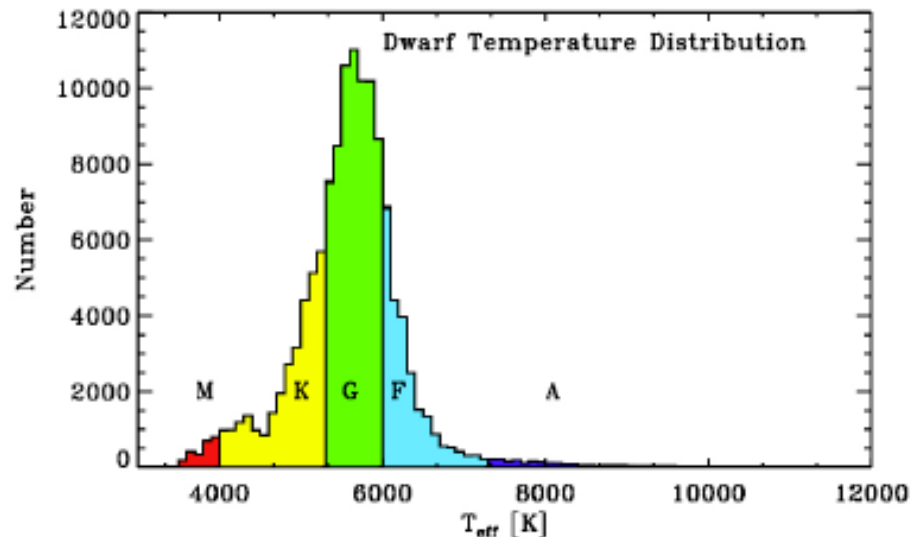
17,000 Giants

Separated by KIC

photometry used to
estimate T_{eff} and $\log g$

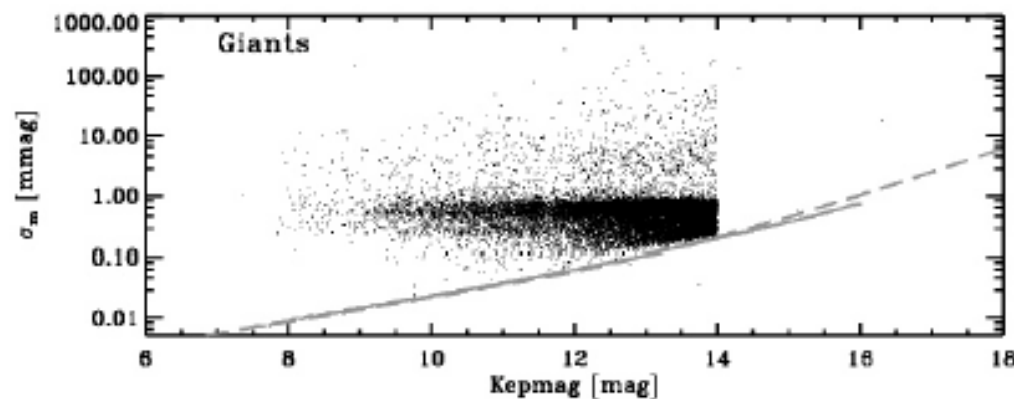
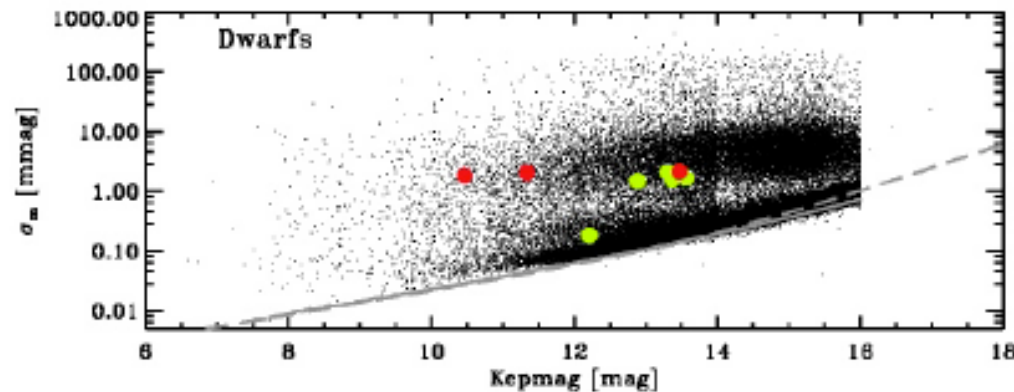
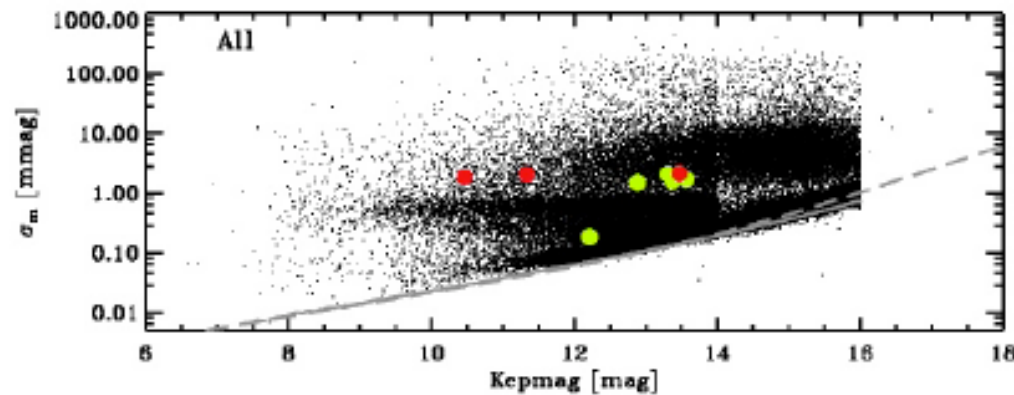


Stars
separated by
spectral type
within each
group

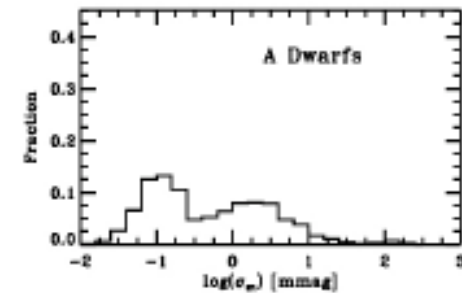
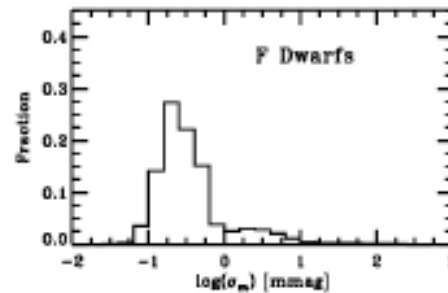
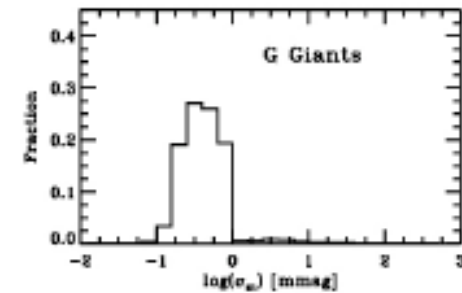
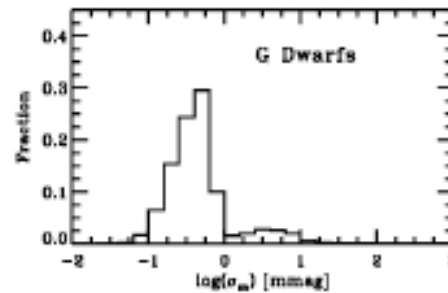
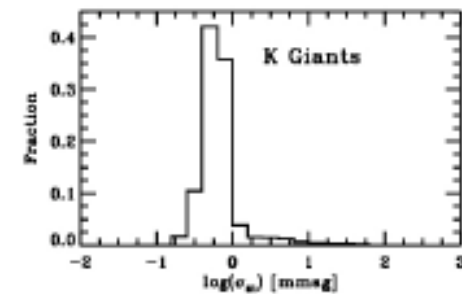
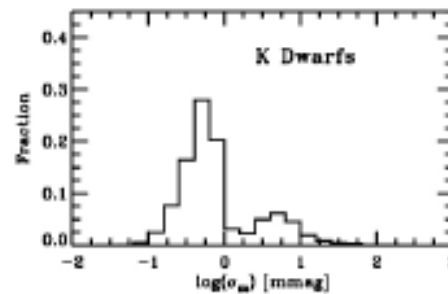
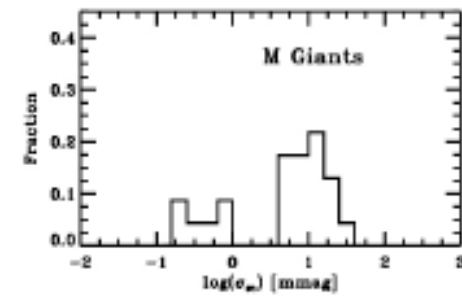
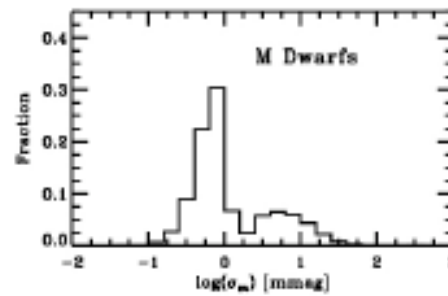


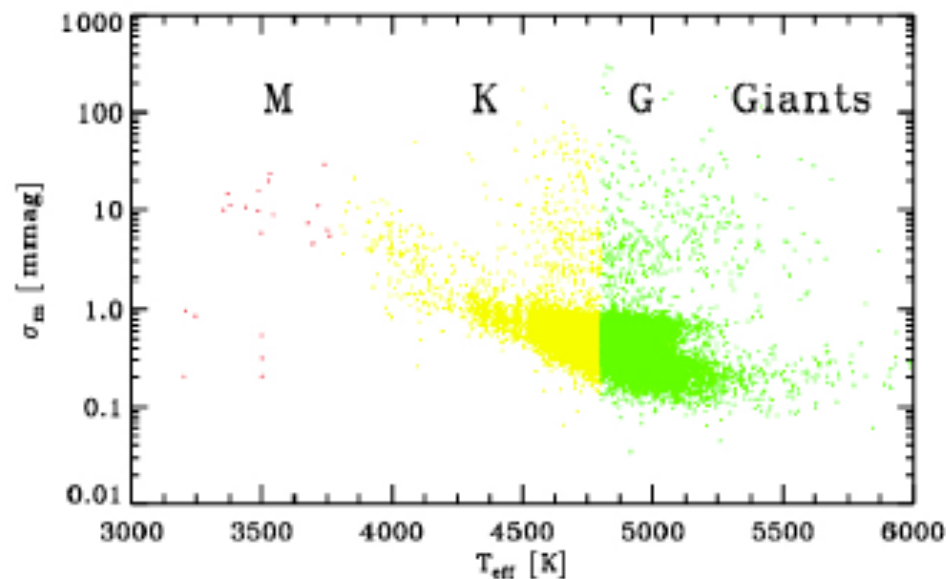
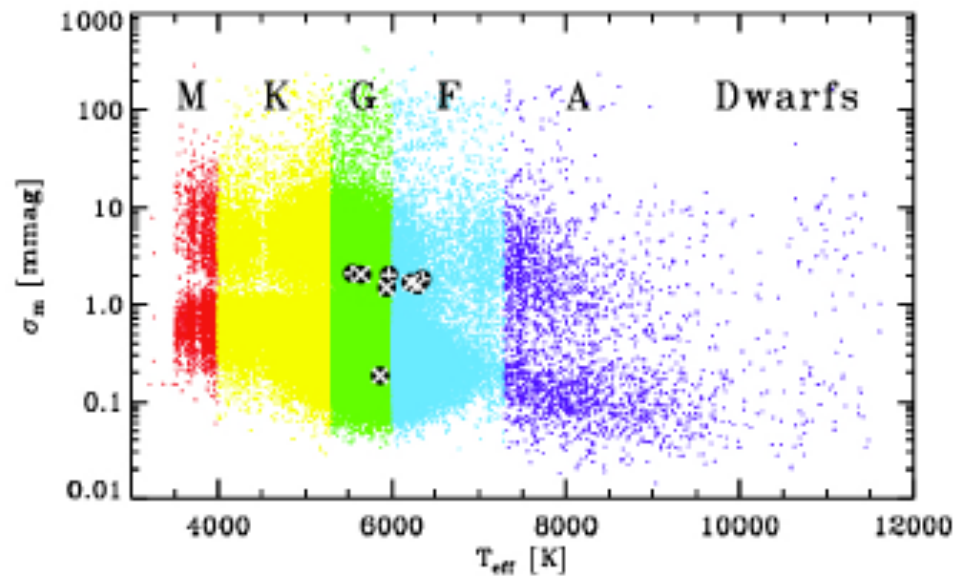
Photometric dispersion vs. Kepler magnitude

Colored dots are exoplanet host stars. The grey lines are two measures of the median uncertainty for the data.



Distribution (Log) of the photometric dispersion separated by Teff, log g



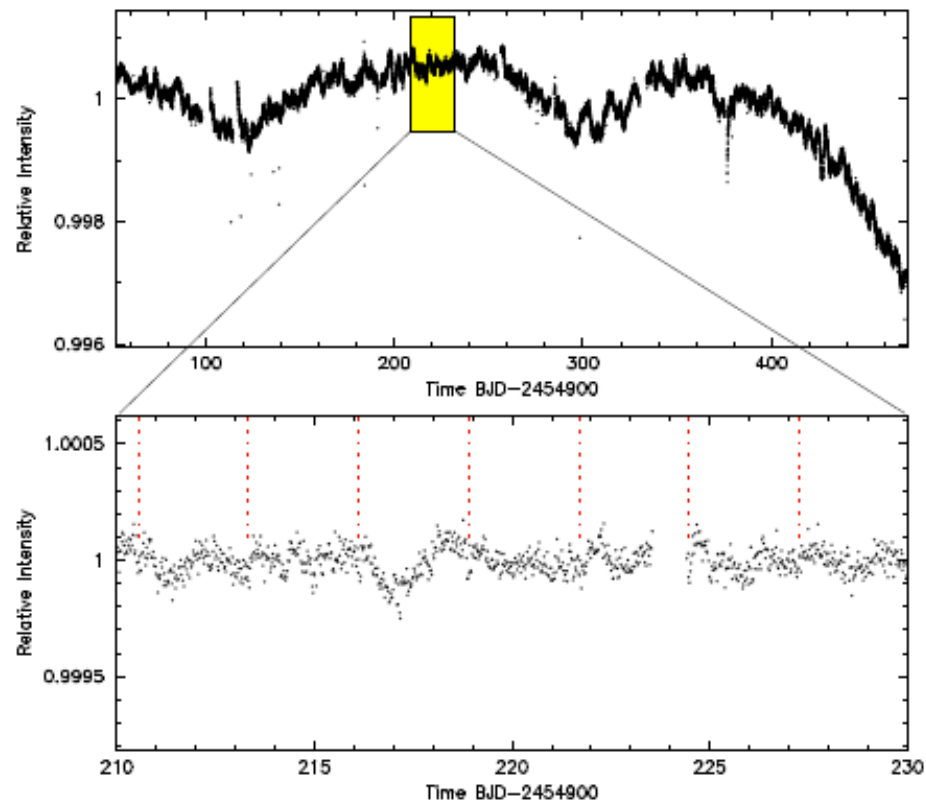


Photometric
dispersion for
dwarfs, giants
separated by
Teff.

Known
exoplanets
marked on top

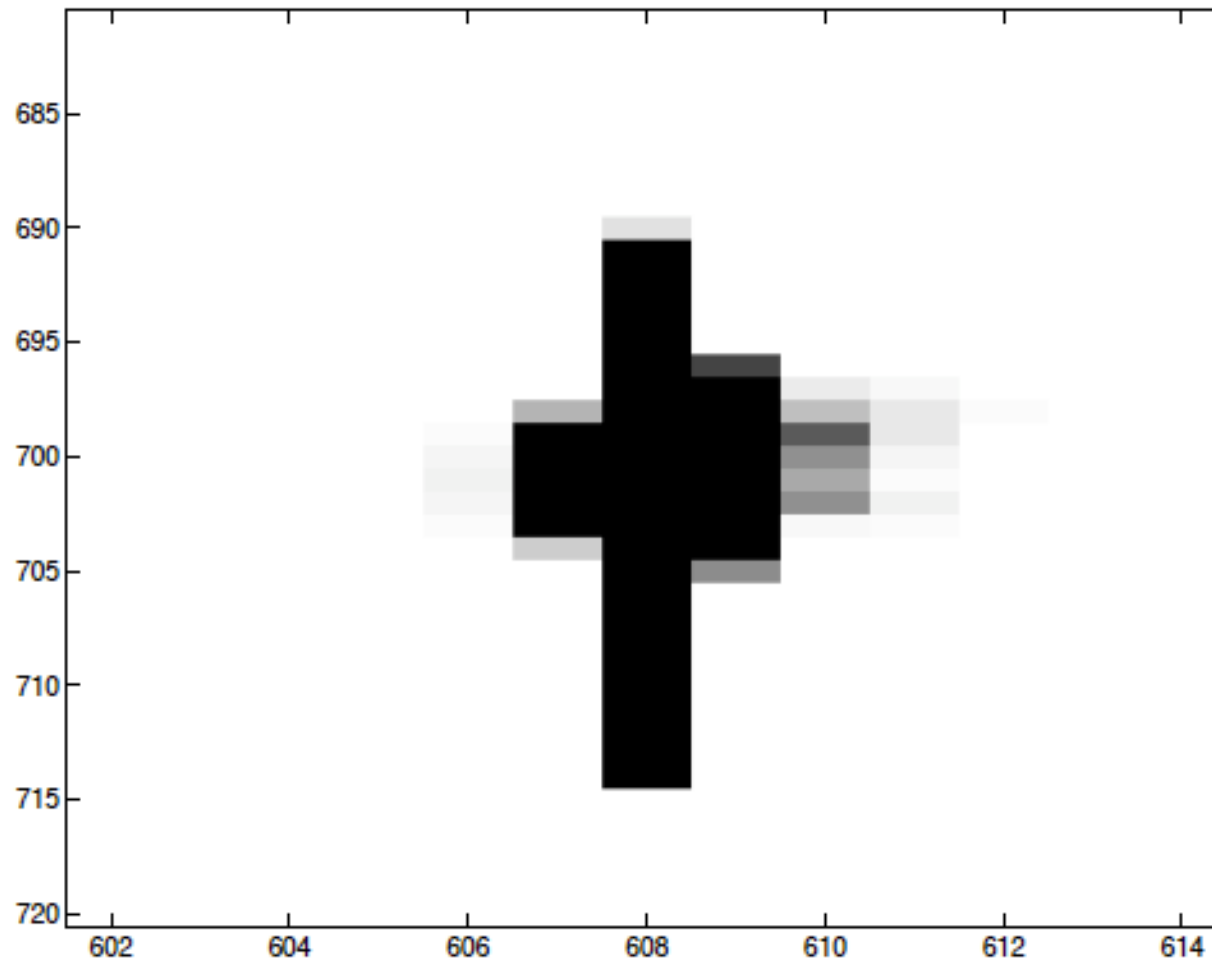
Stellar Sample Results

- Using ~140,000 30-min sampled, 33 day long Kepler light curves, we find,
 - 25% of all dwarfs are variable, 100% for the bright stars
 - G dwarfs are the most stable, floor ≤ 0.04 mmag
 - All giants are variable
 - (floor $\sim 0.1, 0.3, 10$ mmag for G,K,M)
 - Variability fraction increases from 1 day to 33 days
 - Stars closer to galactic plane are more variable
 - May be real (age?) or higher unresolved background

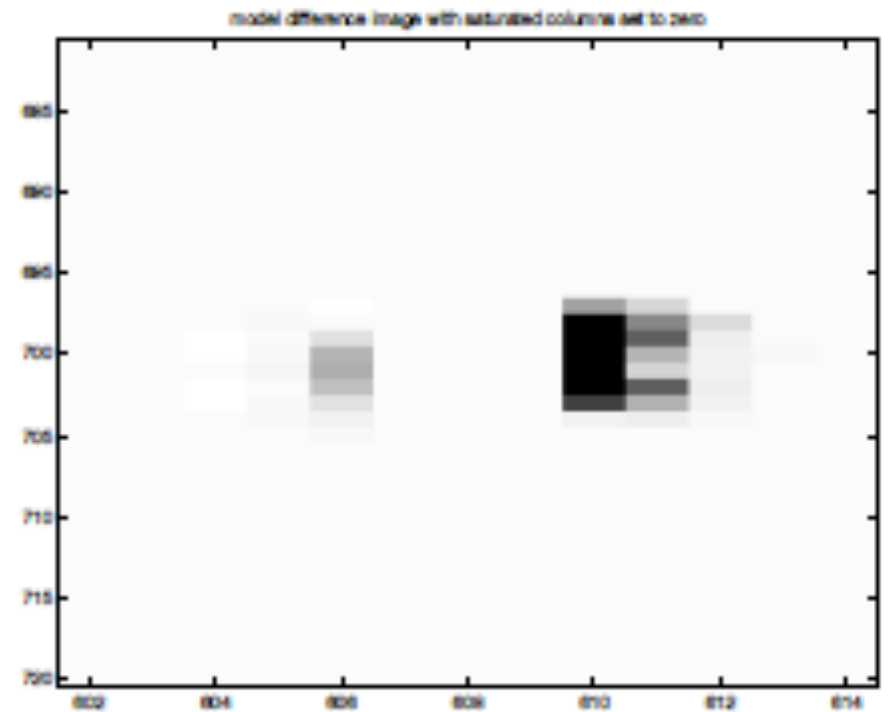
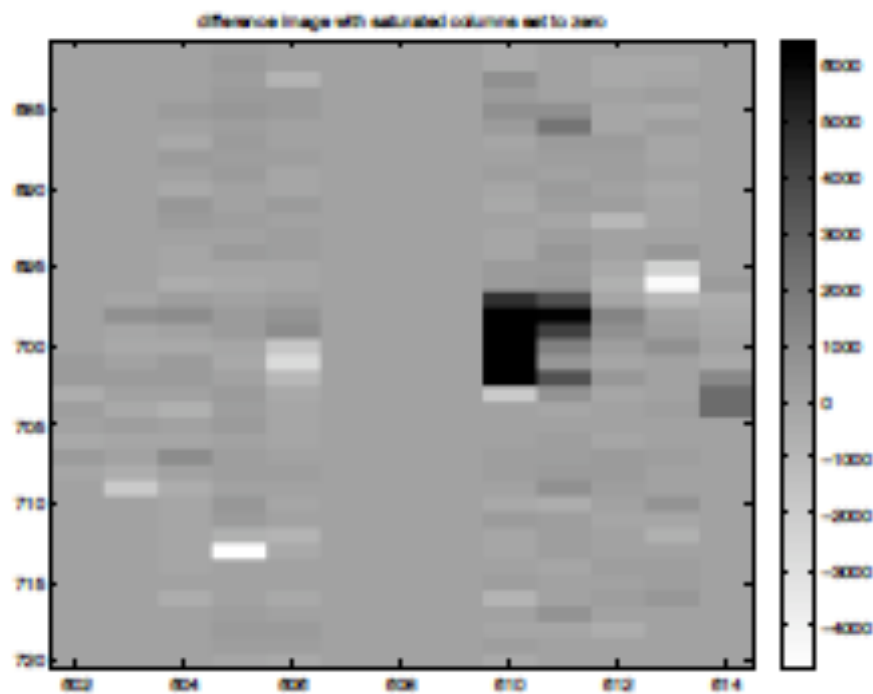


Star with
exoplanet
candidate.
(top) Raw light
curve,
(middle) zoom

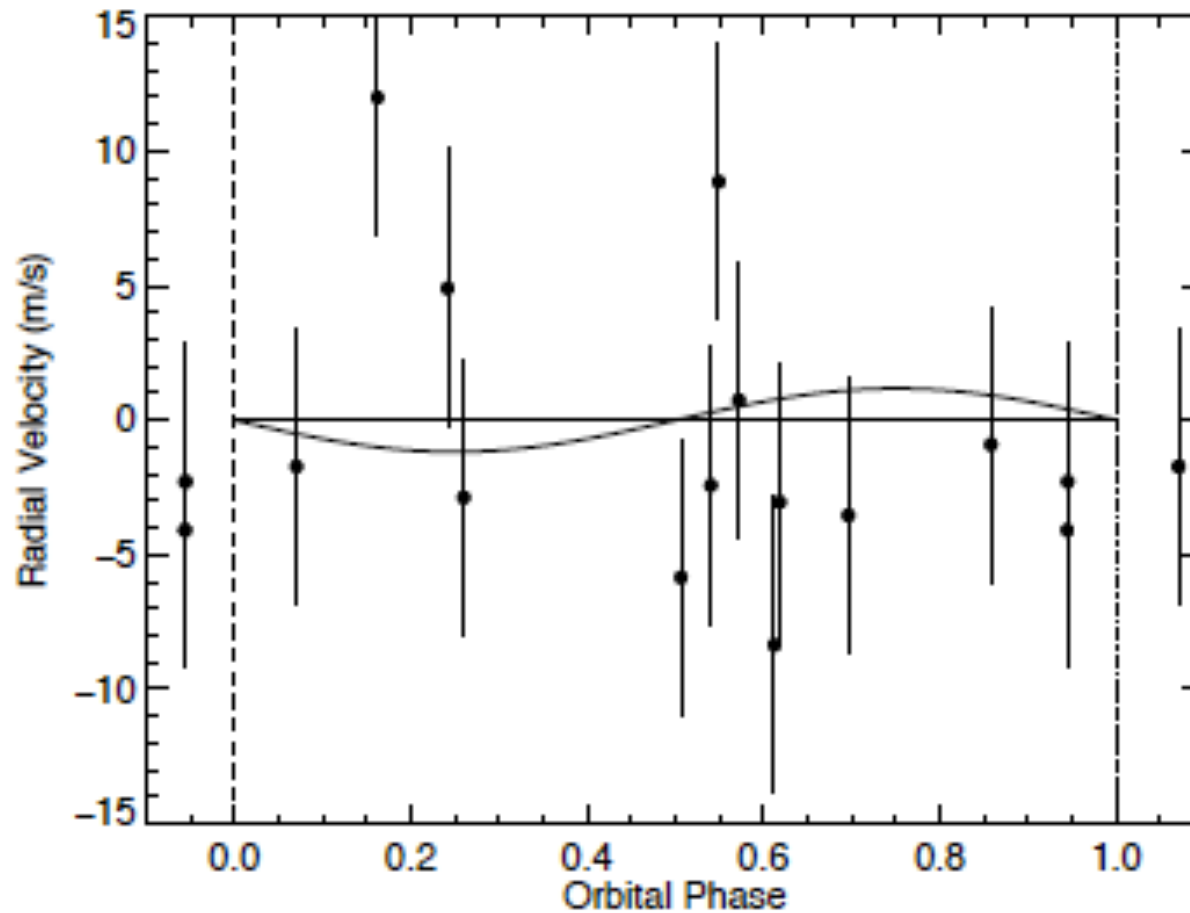
Kepler Saturated Image

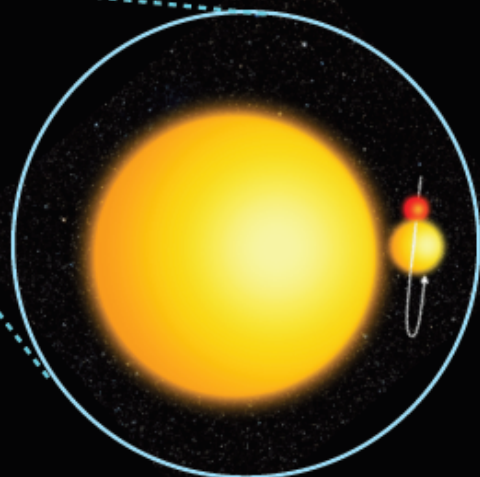
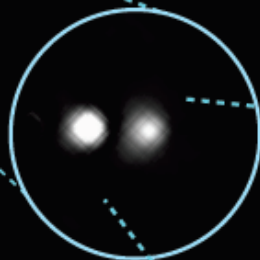
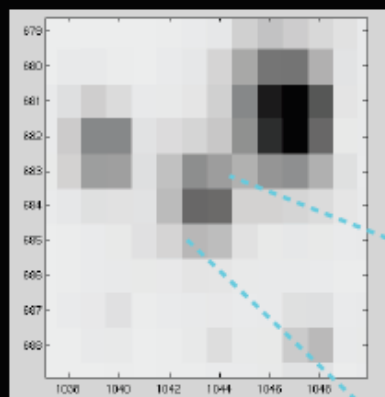


Kepler Difference image – Real, Model



Keck Hi-Res velocities – not even close

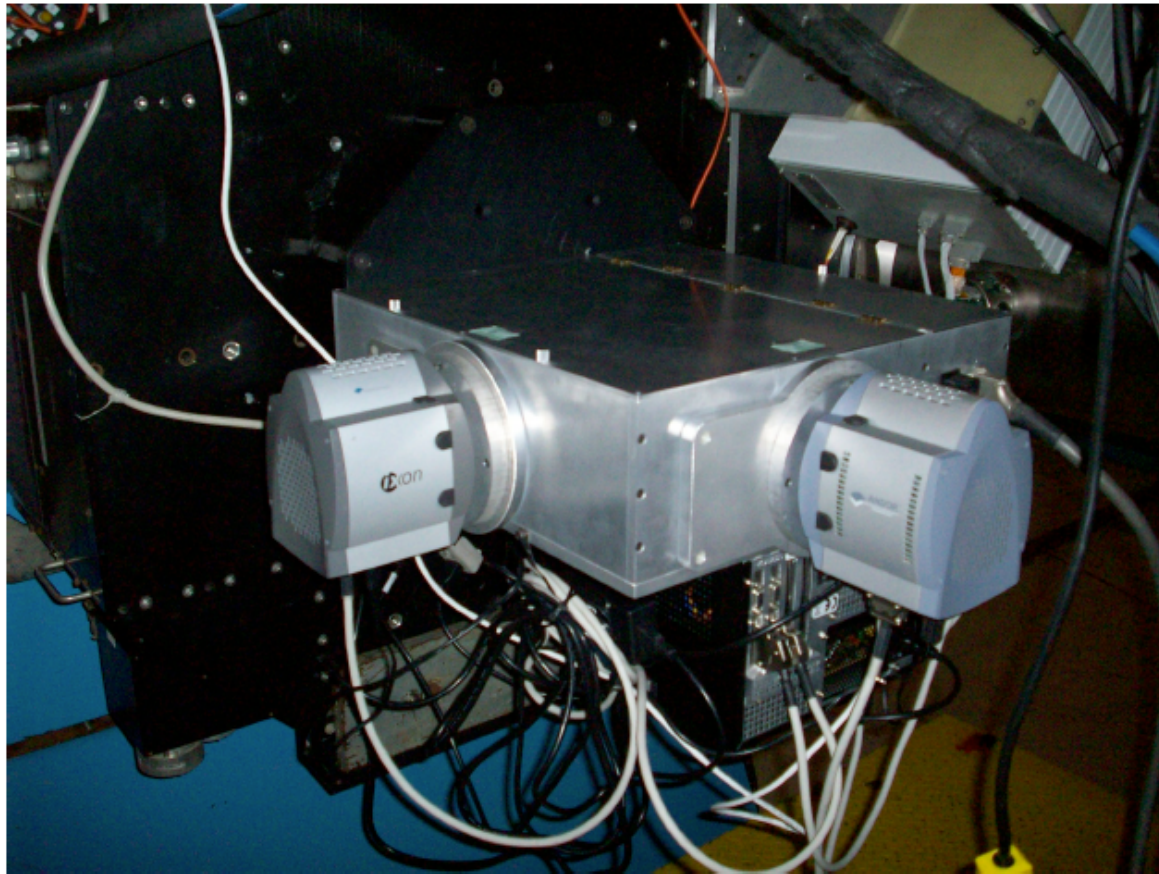




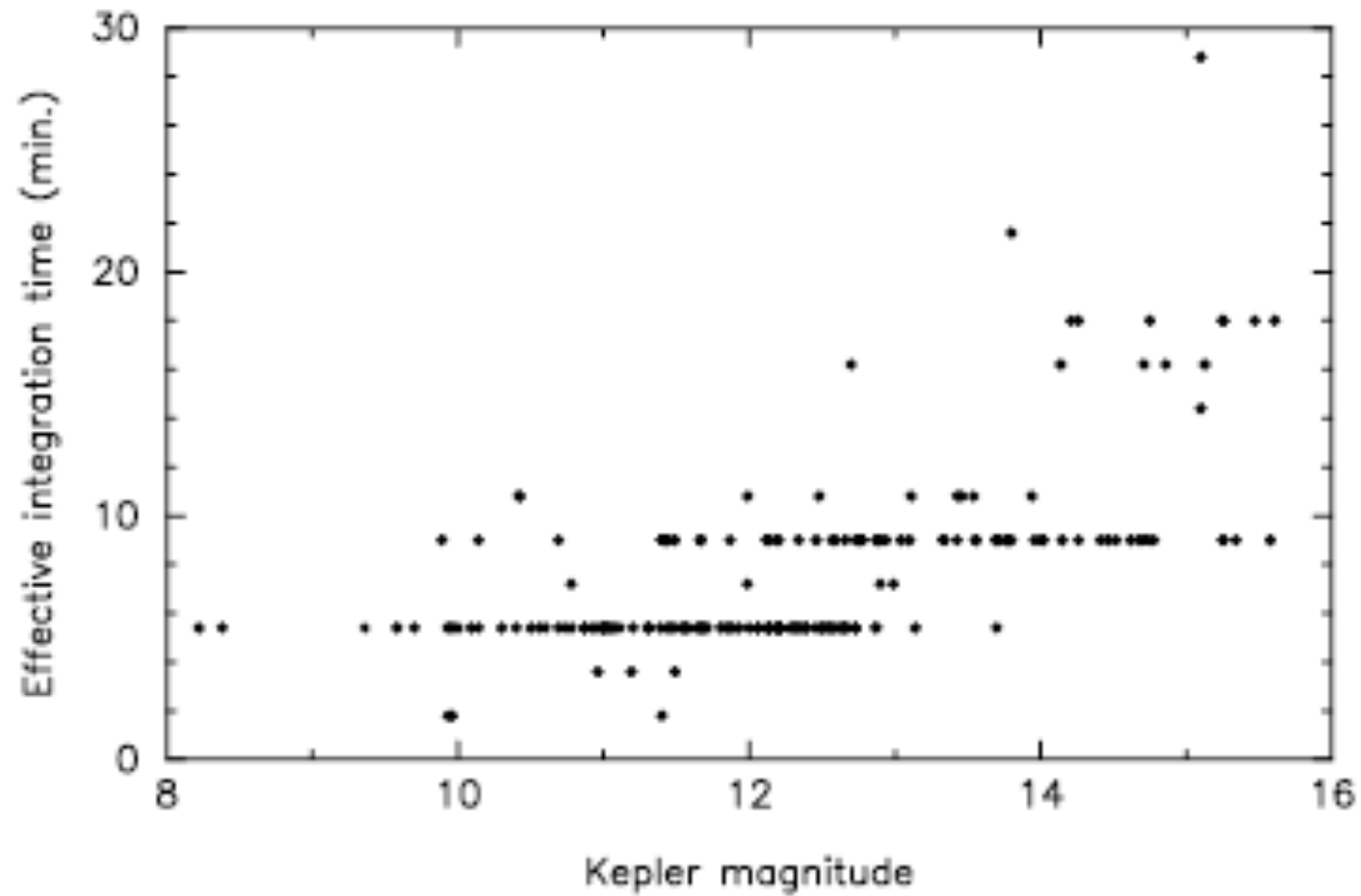
Hi-Res Observations

- Kepler exoplanet candidate stars are followed up by ground-based observations
- High resolution imaging is key for small exoplanets
- Speckle observations performed at WIYN telescope
- Use dual channel EMCCD speckle camera

Dual Channel Speckle Camera at WIYN Telescope



Effective Int. Time for Speckle



Delta Mag for Speckle Observations

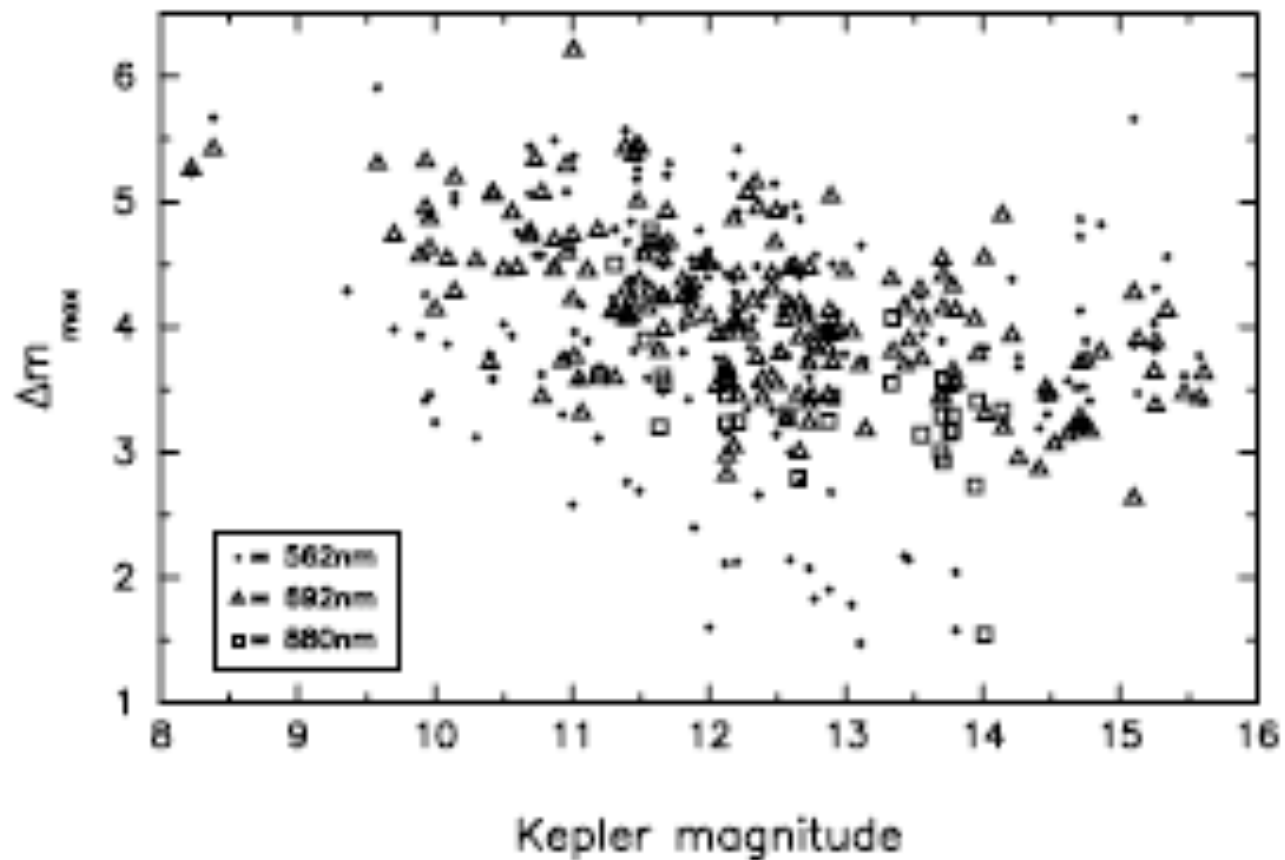
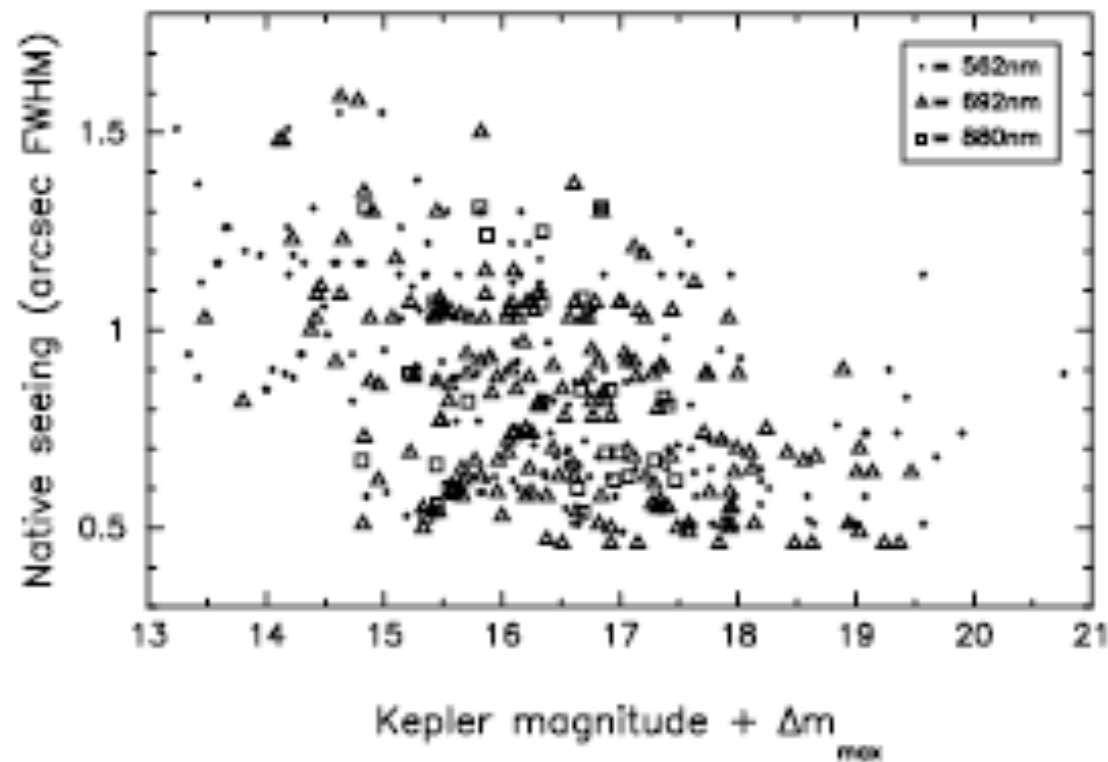
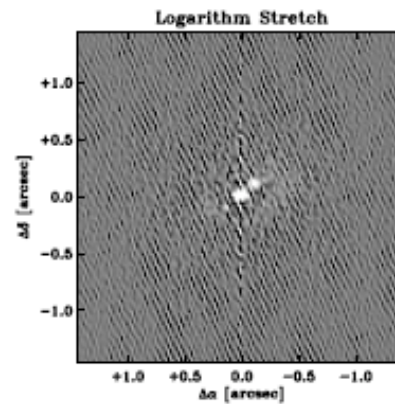
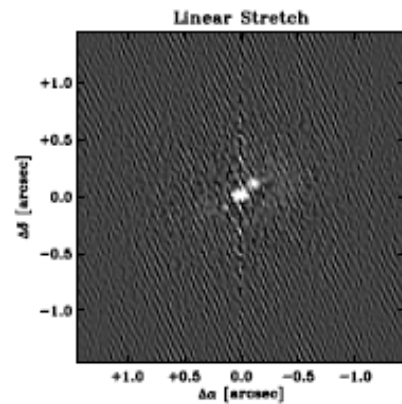
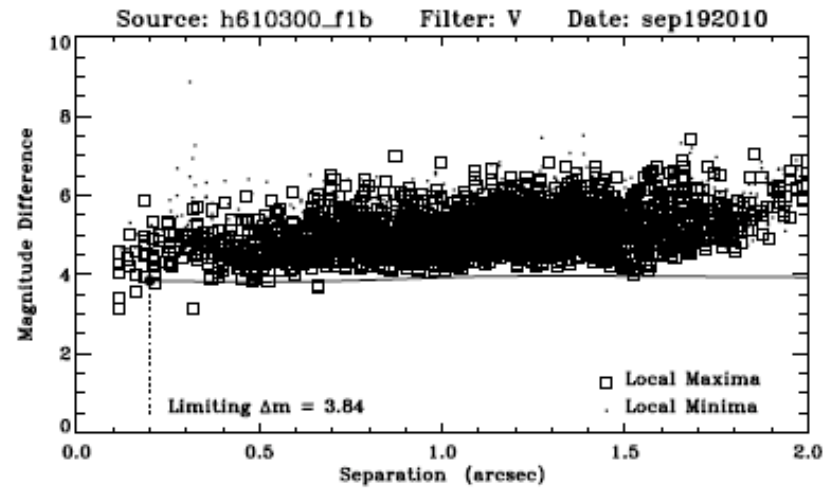


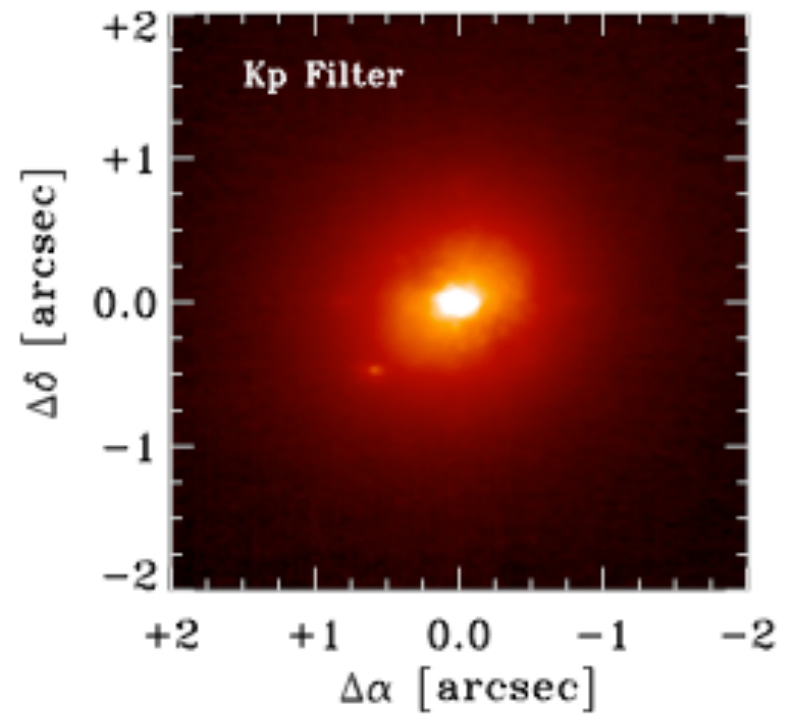
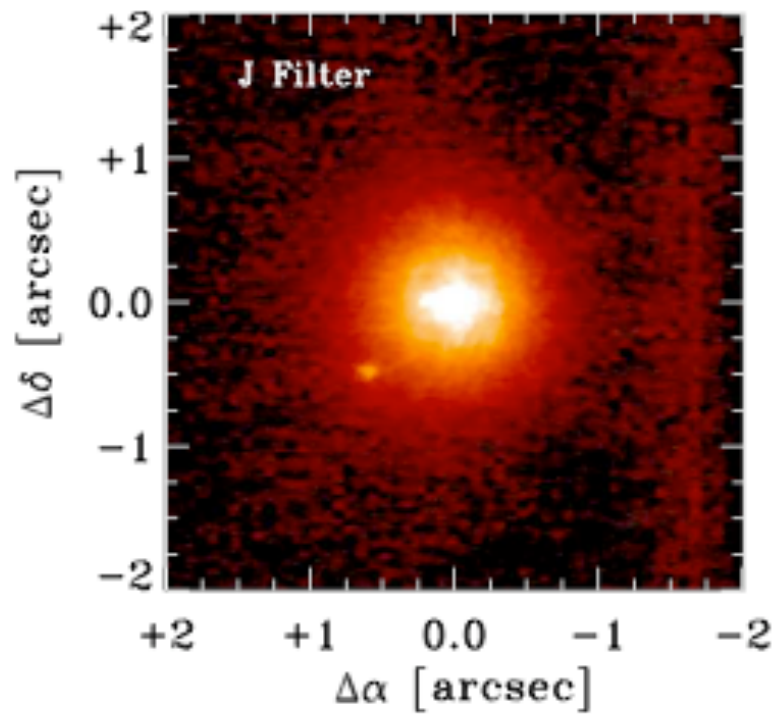
Plate limit for Speckle Observations

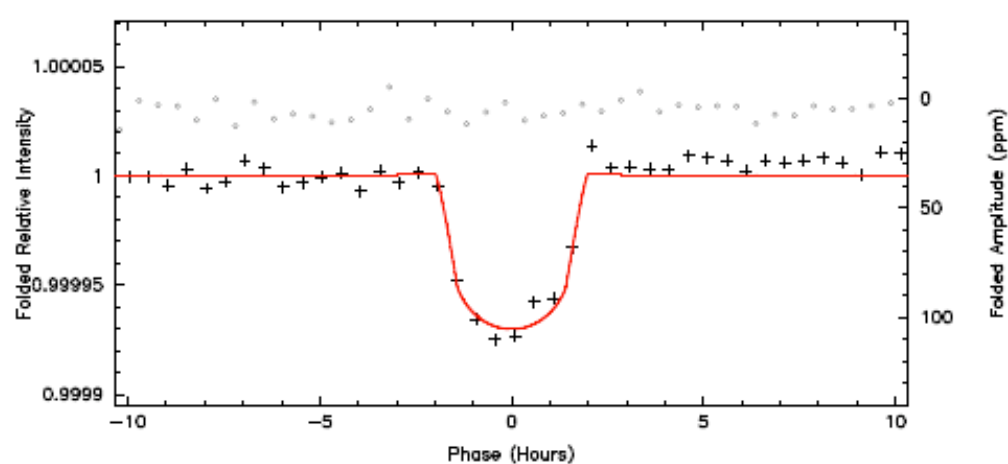
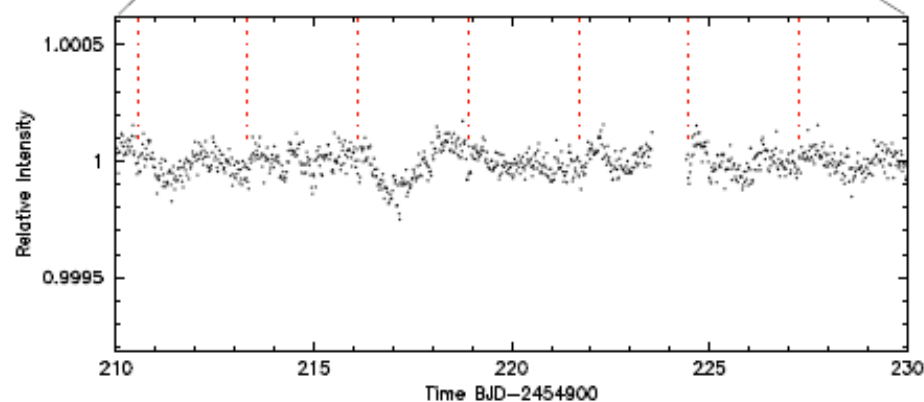
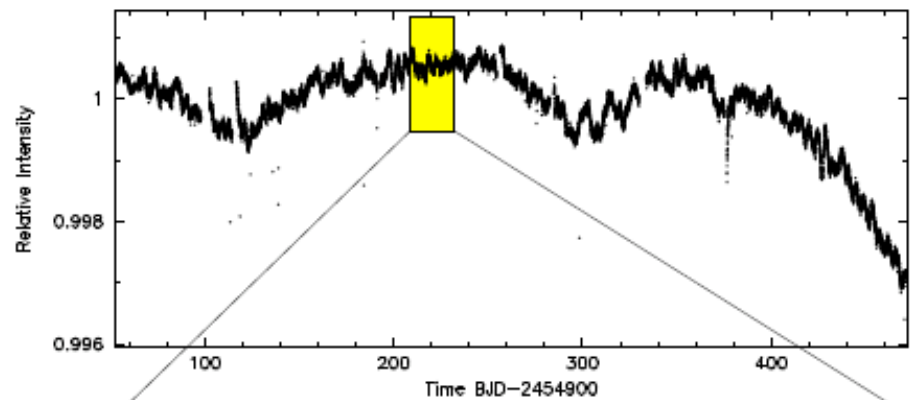


Reconstructed Speckle Image



Keck AO – J, K bands

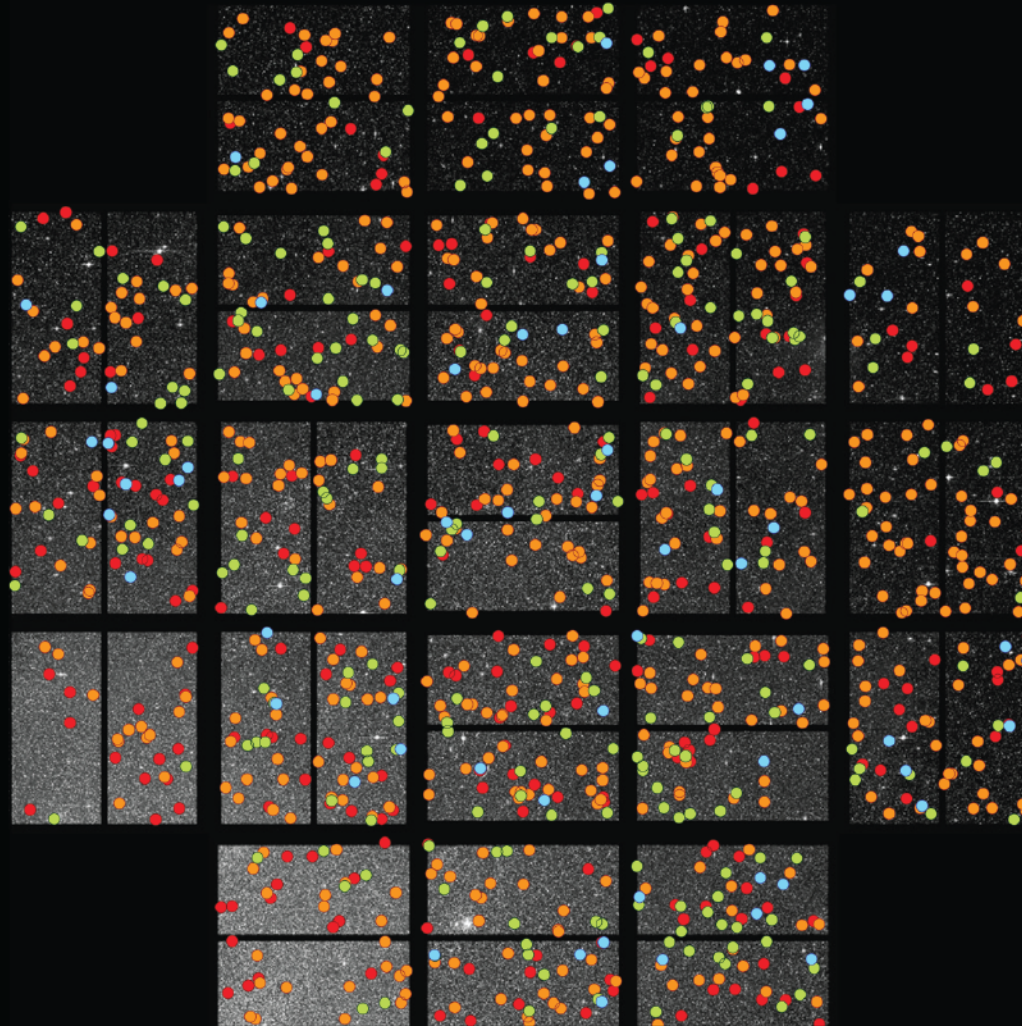




F6IV star with
1.6Re
candidate.
(top) Raw light
curve,
(middle) zoom,
(bottom)
phased transit

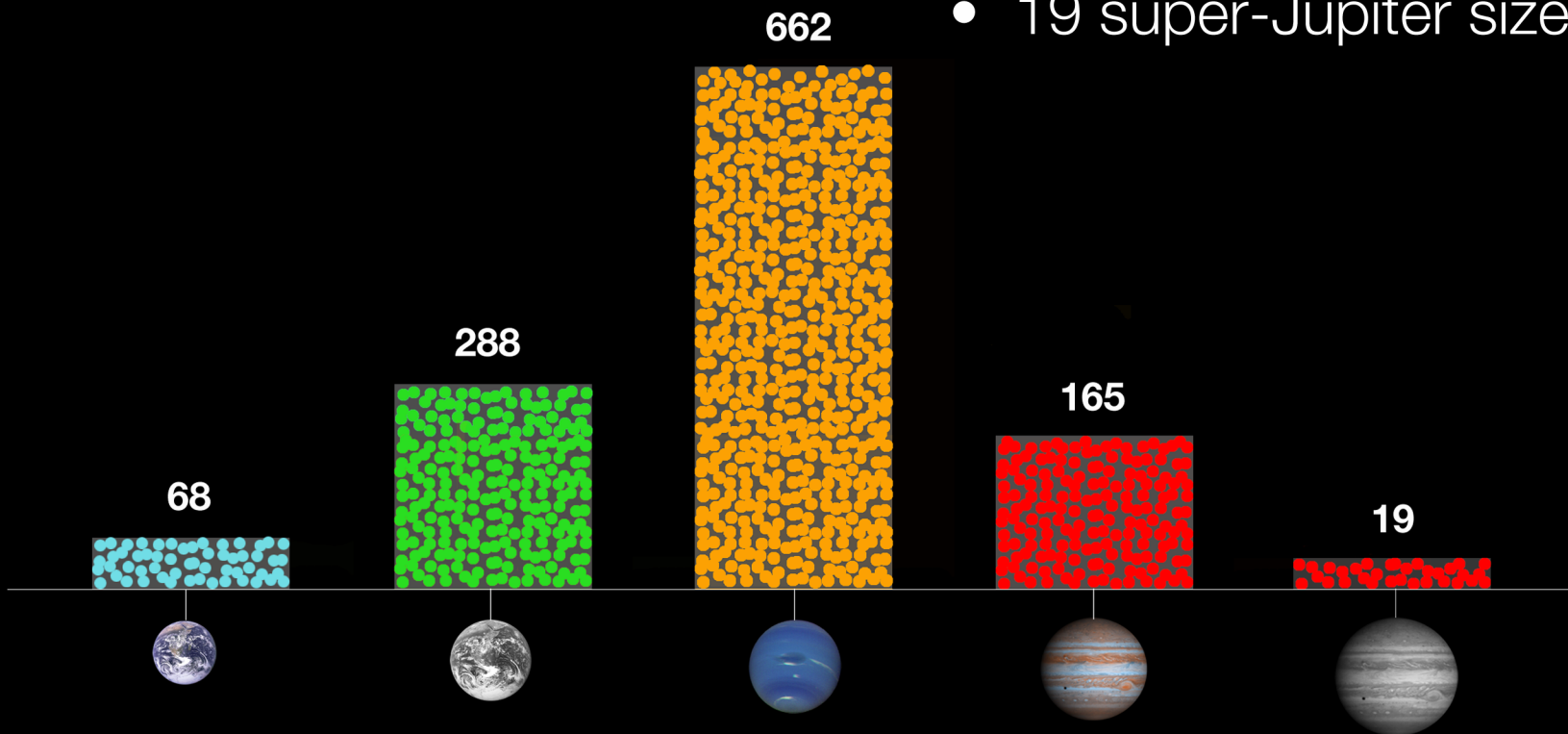
Locations of Kepler Planet Candidates

- Earth-size
- Super-Earth size
1.25 - 2.0 Earth-size
- Neptune-size
2.0 - 6.0 Earth-size
- Giant-planet size
6.0 - 22 Earth-size

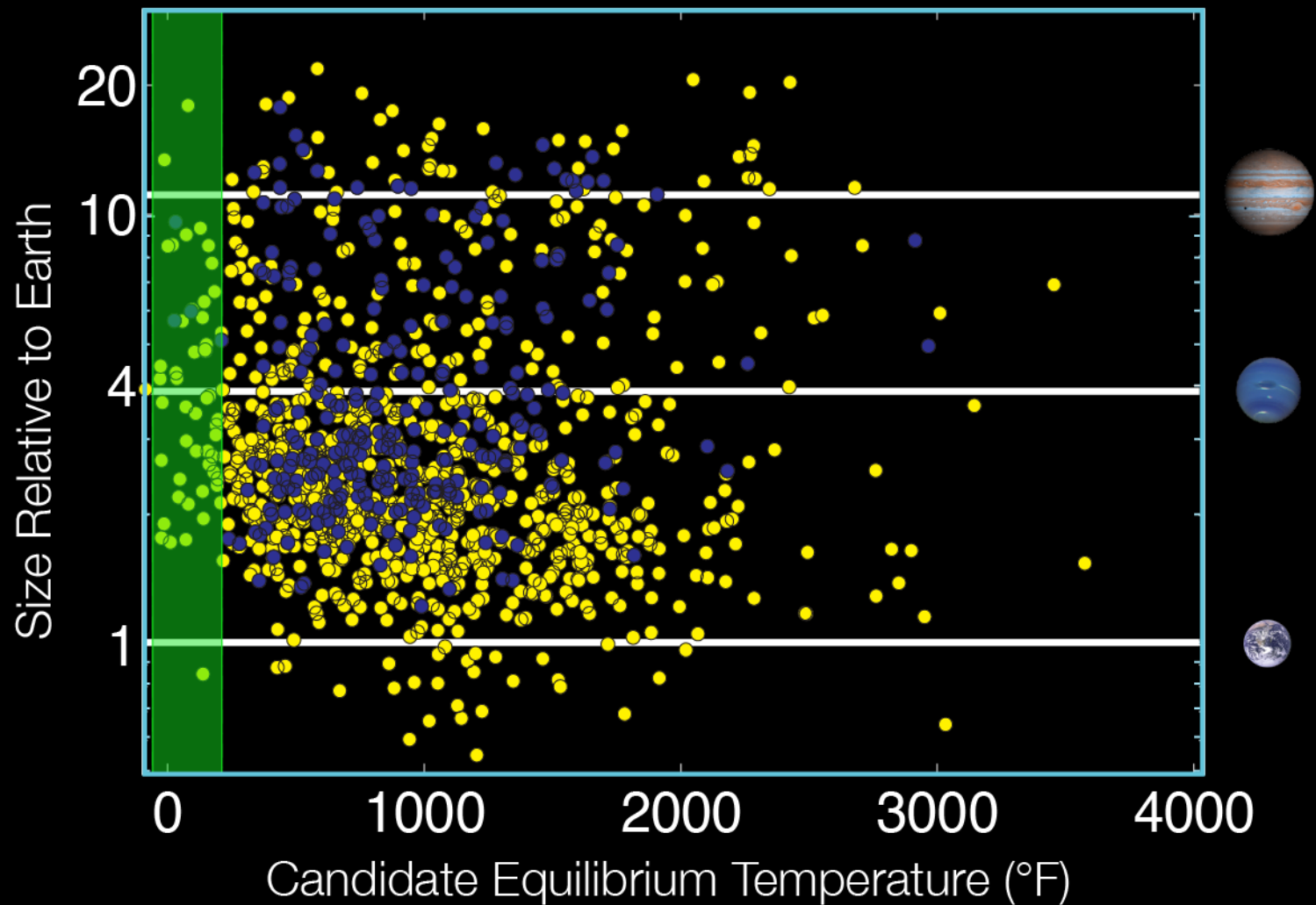


Numbers of Planet Candidates

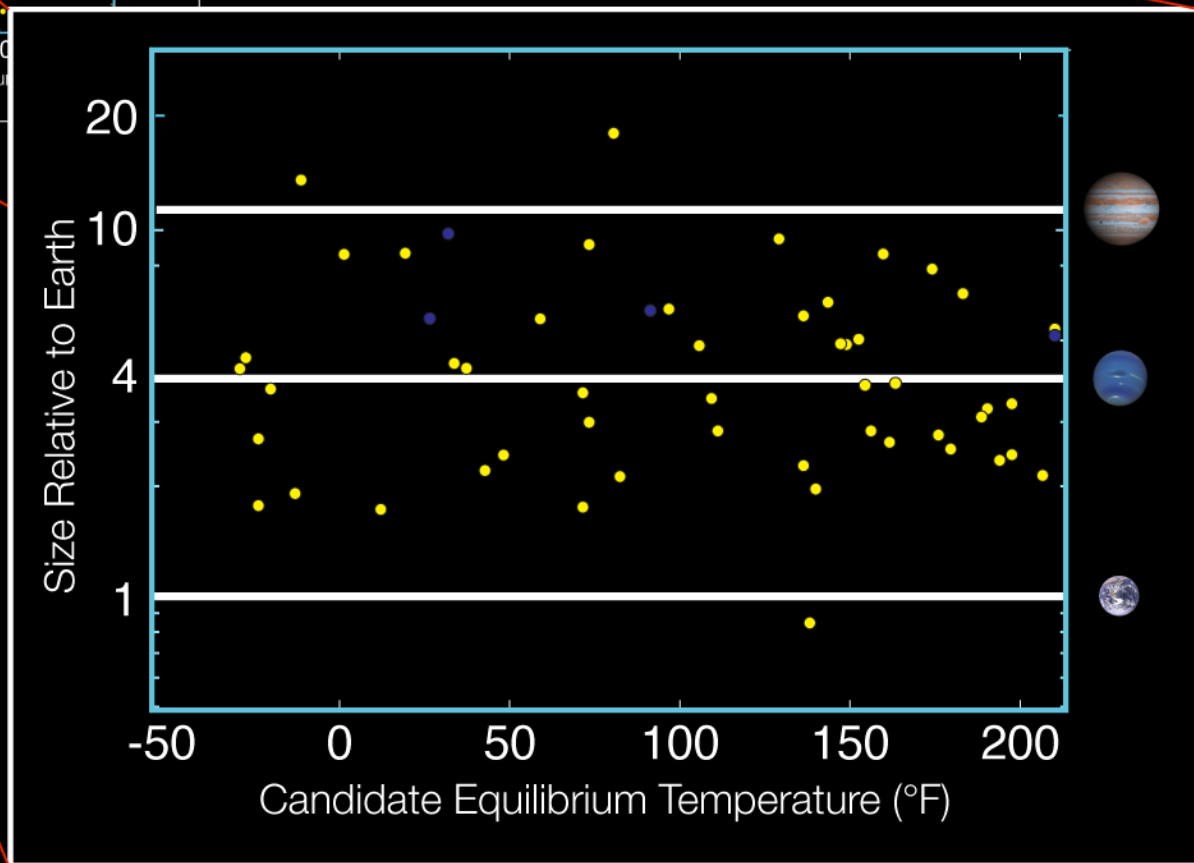
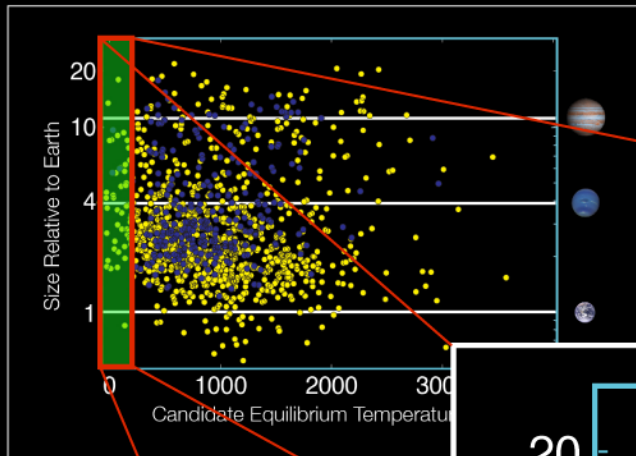
- 68 Earth-size
- 288 super-Earth size
- 662 Neptune size
- 165 Jupiter size
- 19 super-Jupiter size



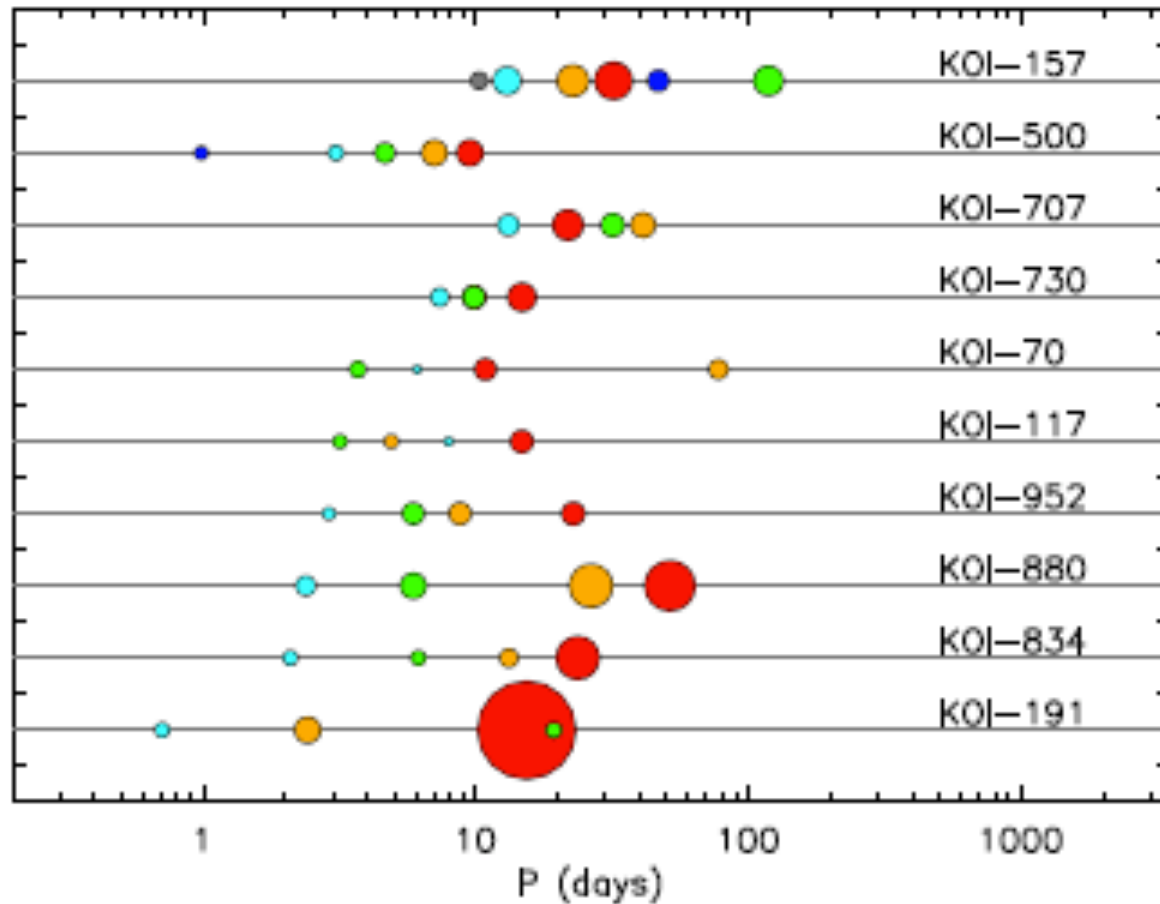
Kepler Candidates as of February 1, 2011



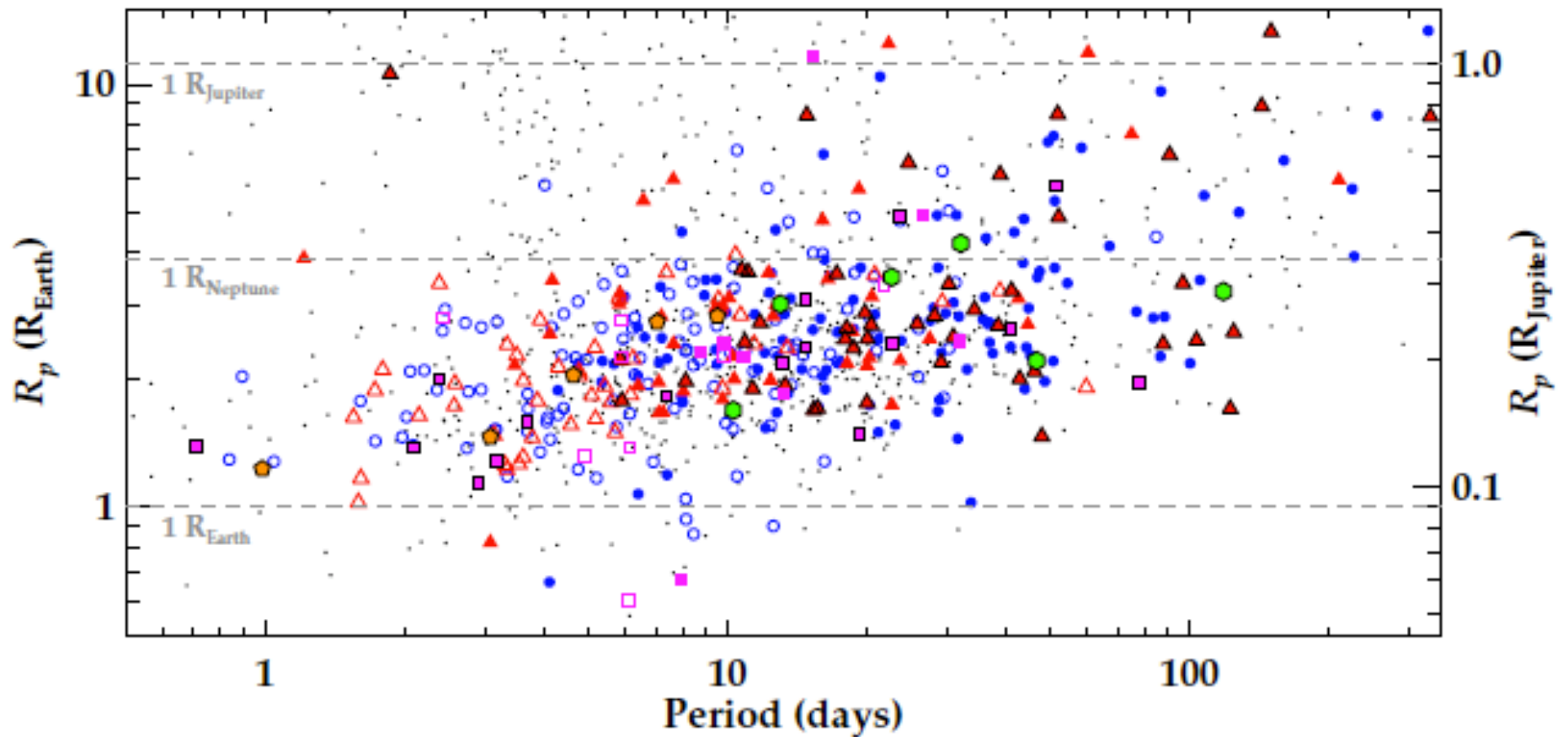
Kepler Planet Candidates In the Habitable Zone

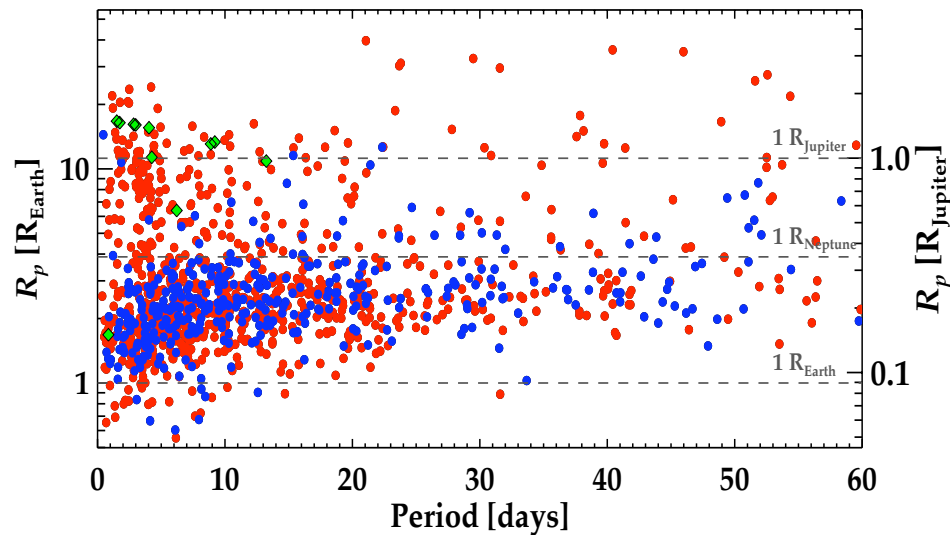
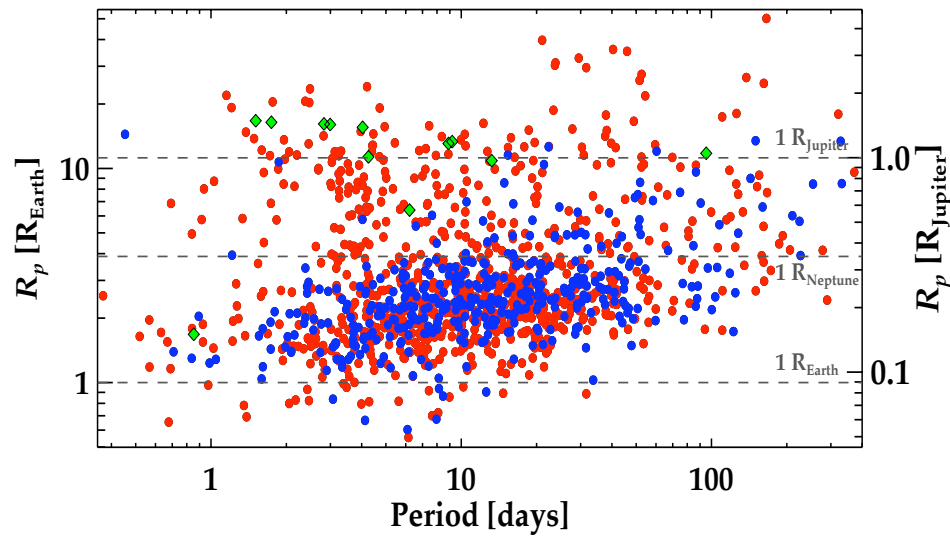


Multiple Planet Systems



Multi's by Period and Radius

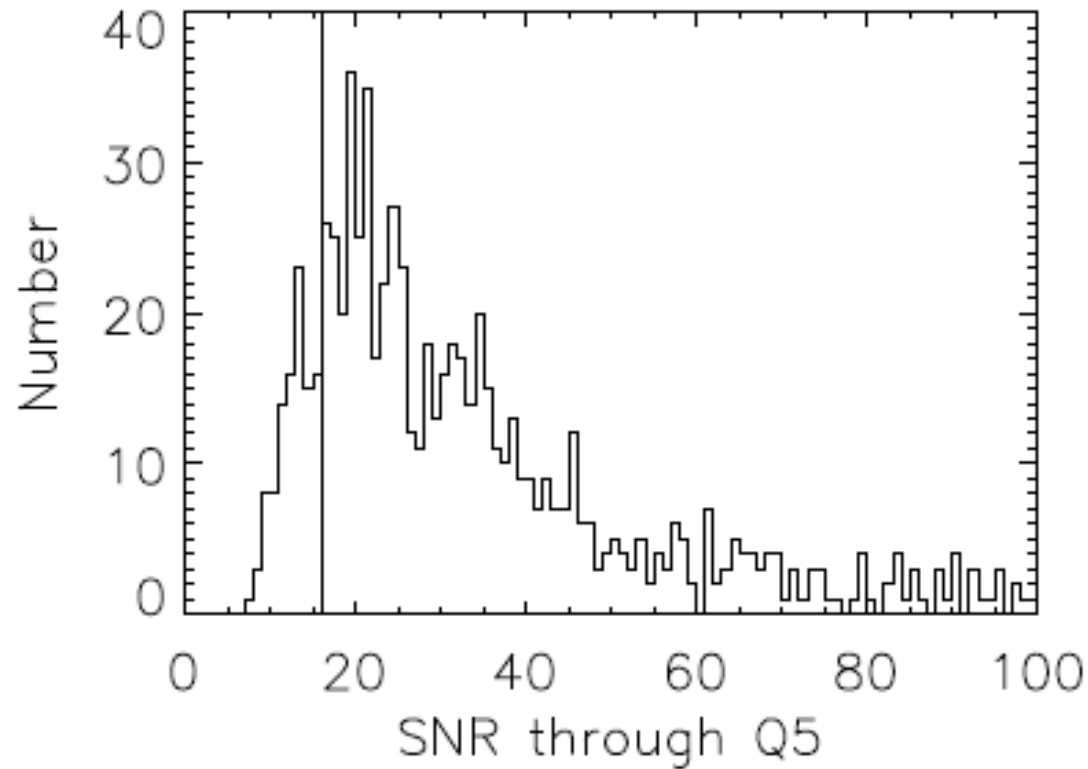




Top log scale
 Bottom linear scale
 Single planets = red
 Multiples = blue
 CoRoT = green

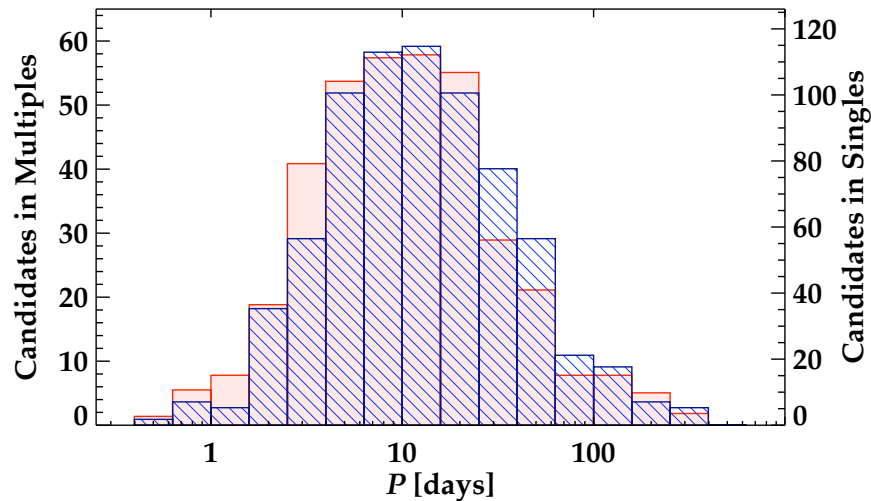
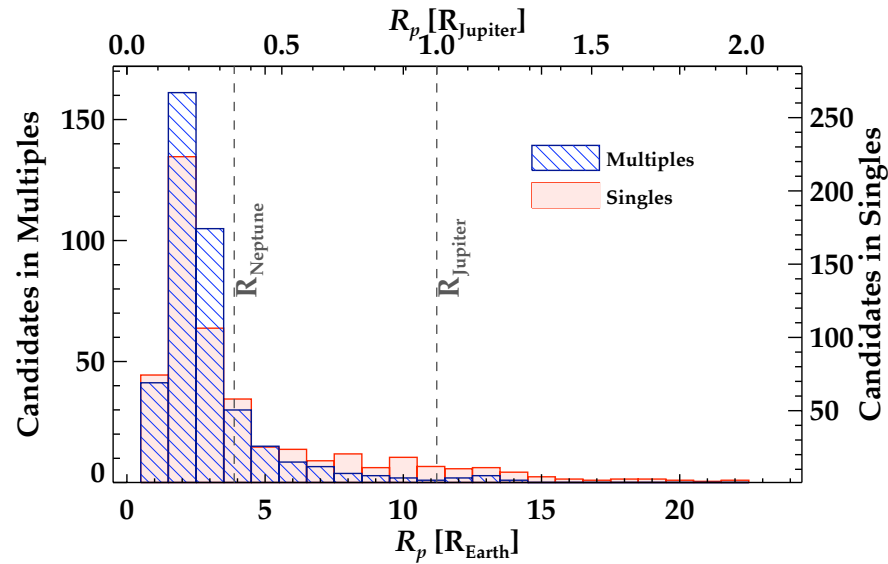
Kepler finds very few
 giant planets in
 systems of multiple
 planets

Lots of Small Planets



Smallest planets still missed due to few low S/N transit events

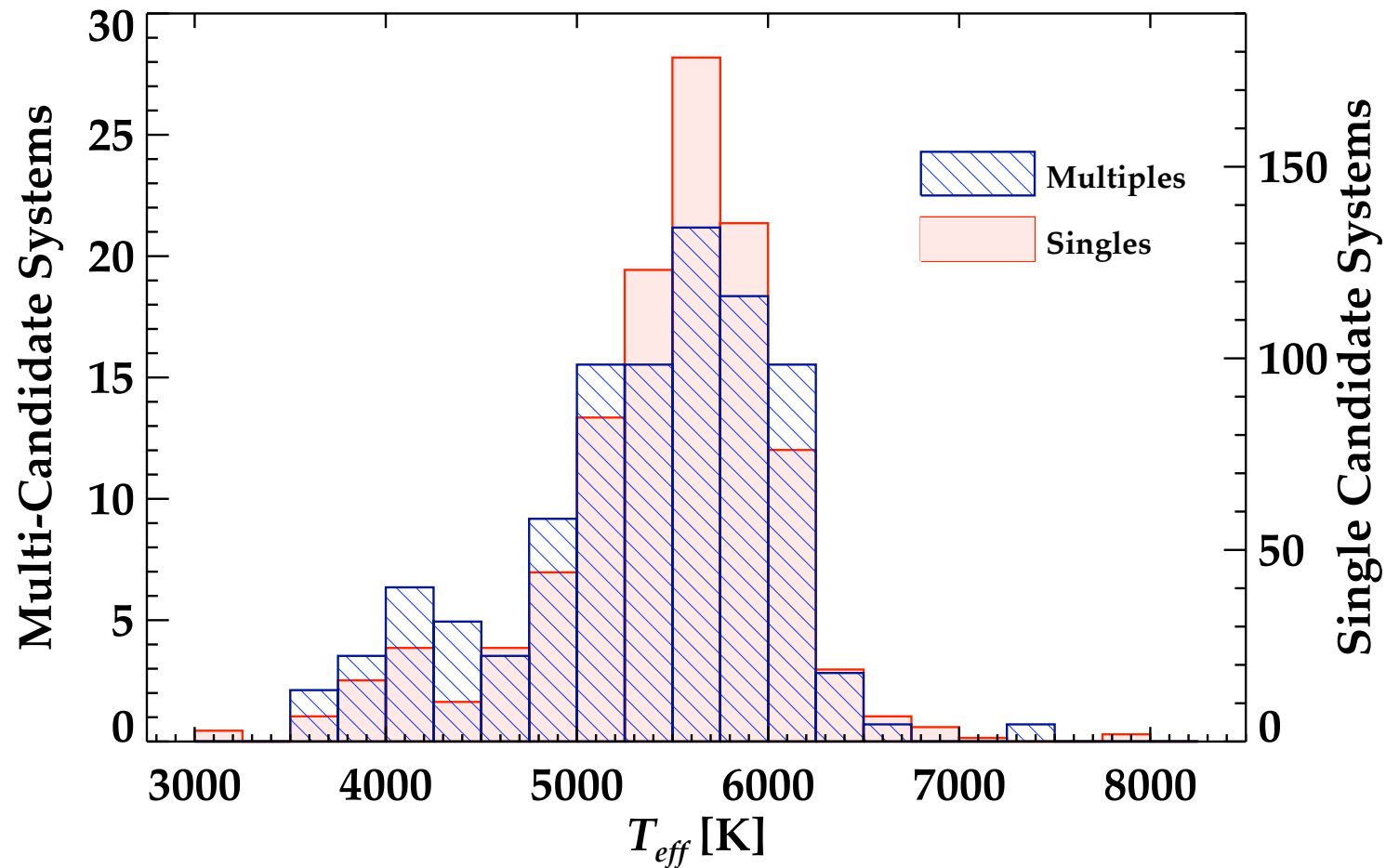
Comparison by Single or Multiple



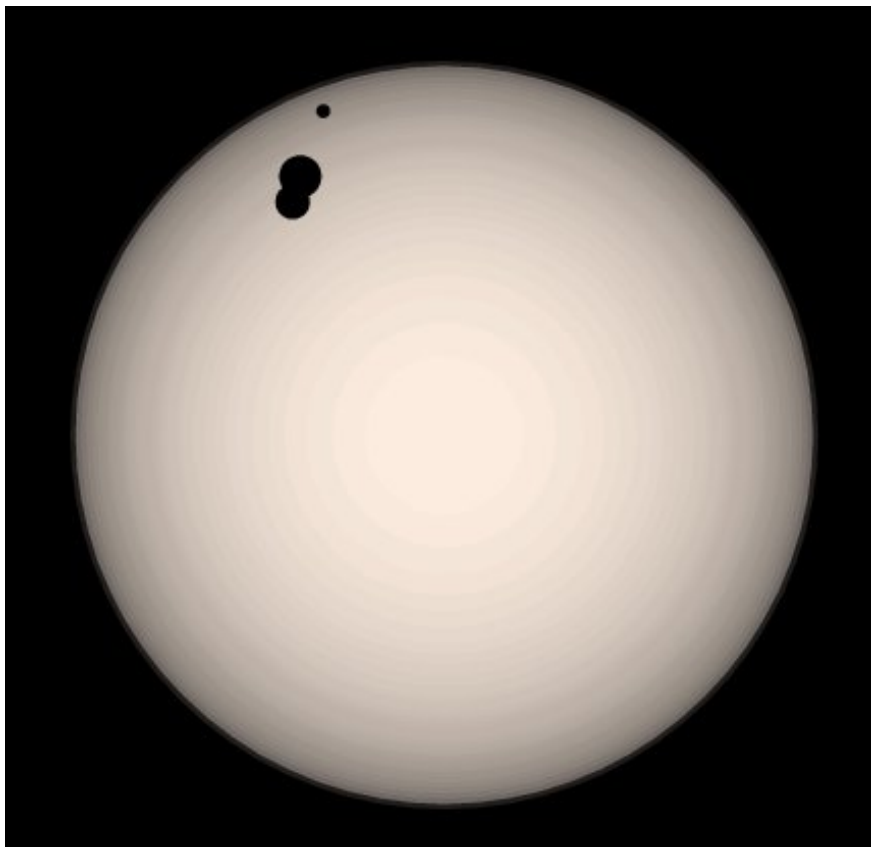
Normalized area
Histograms for
multiple and single
planet systems.

Planets smaller than
Neptune dominate
both samples,
But perhaps more so
for the
multiple systems

Host Star Effective Temperature - a proxy for stellar mass

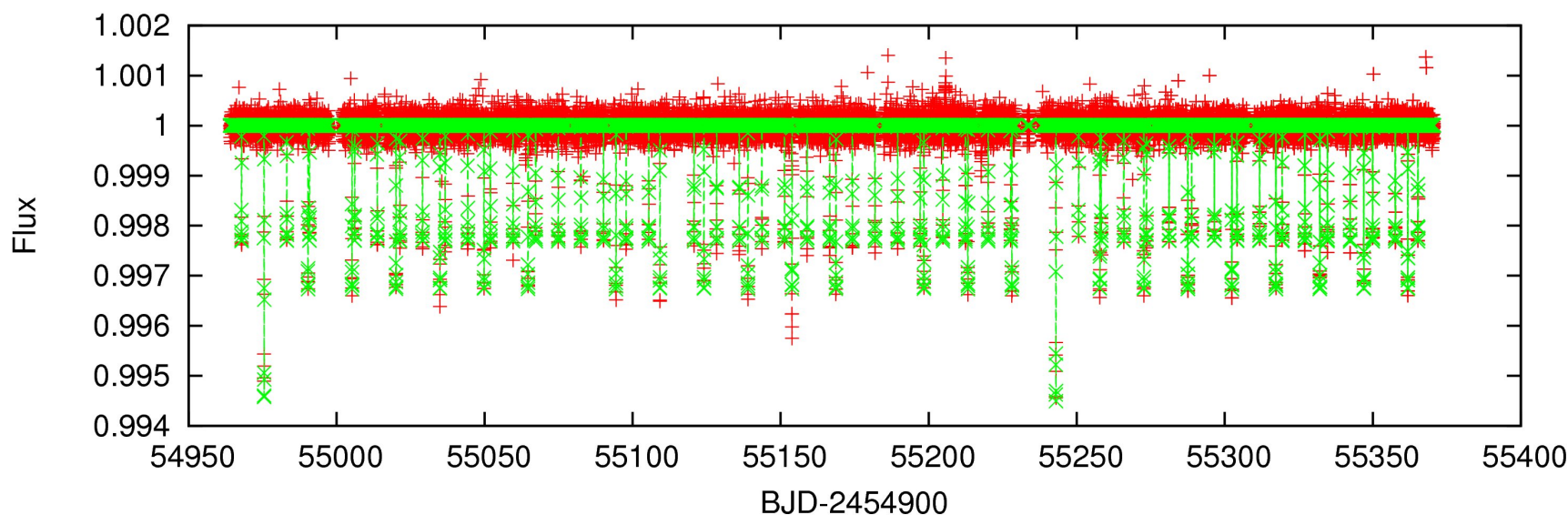


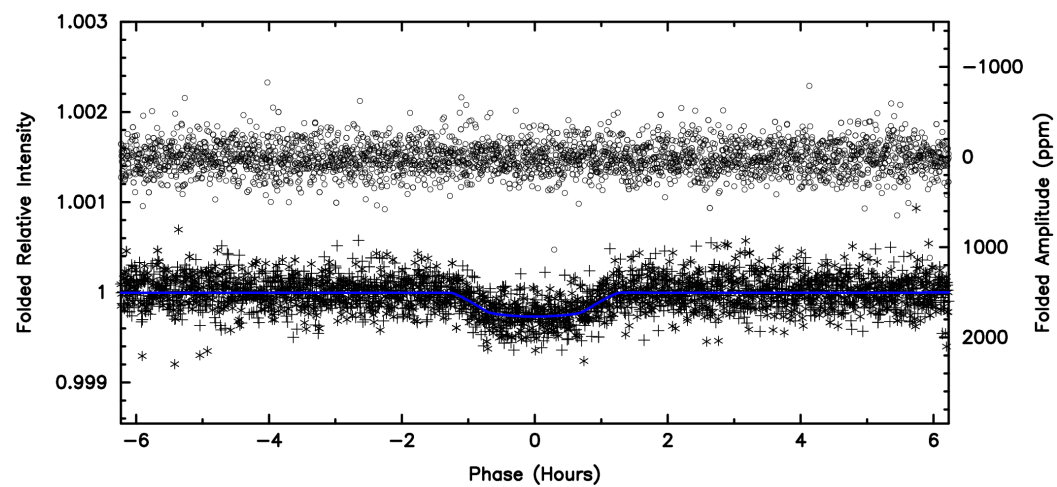
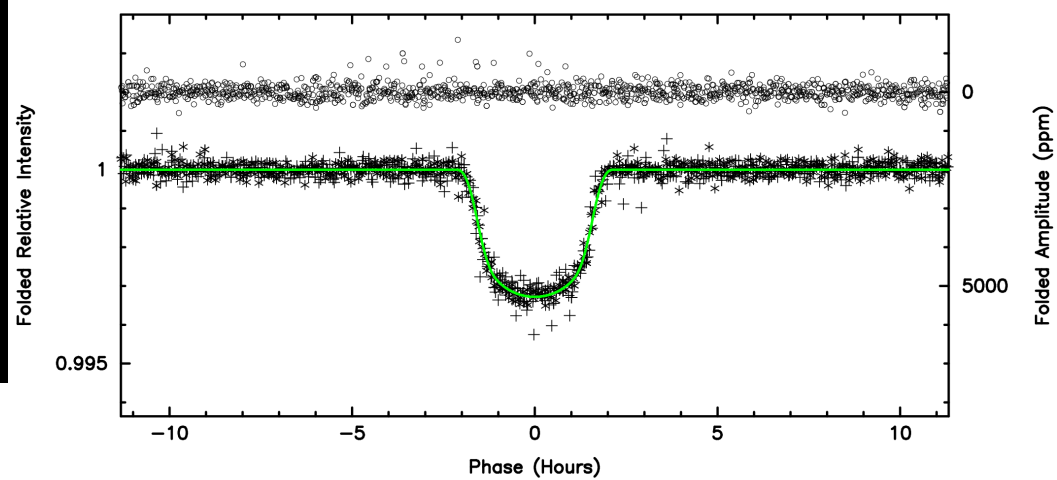
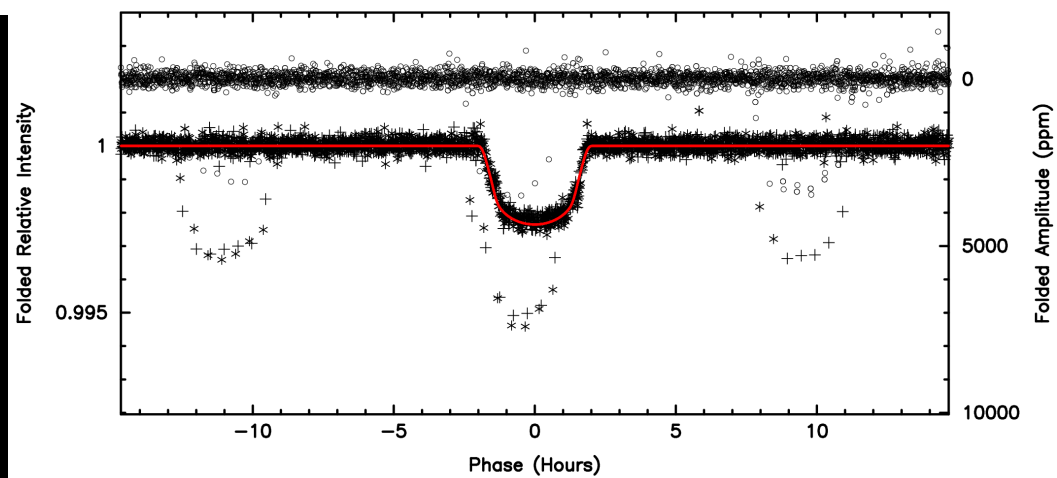
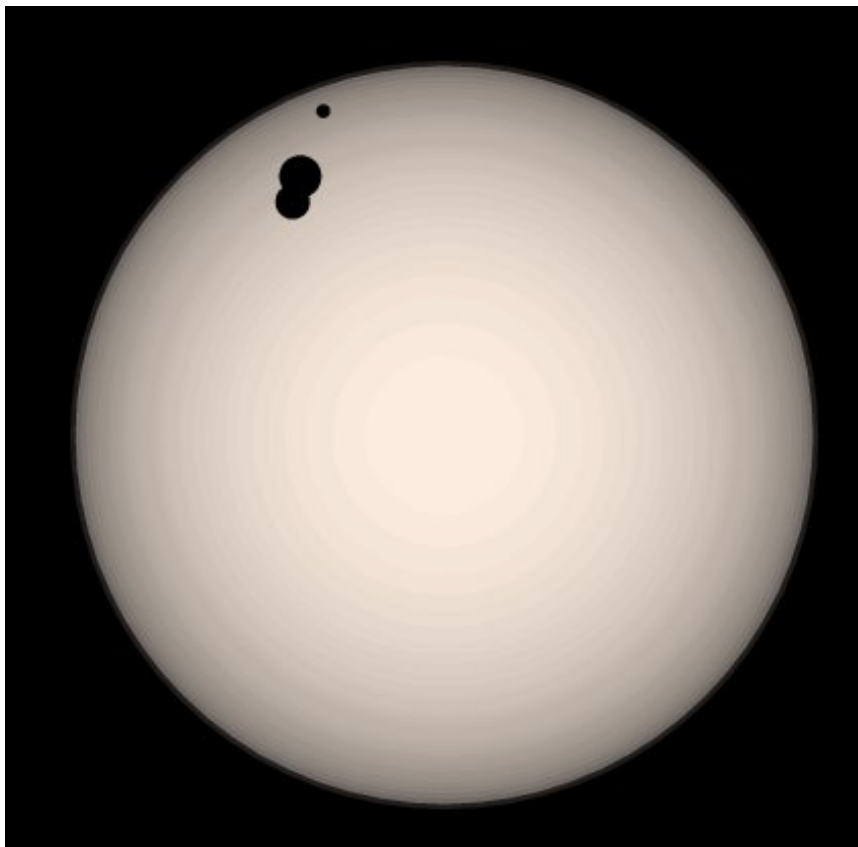
May indicate that single (larger) planets are more common around hotter stars

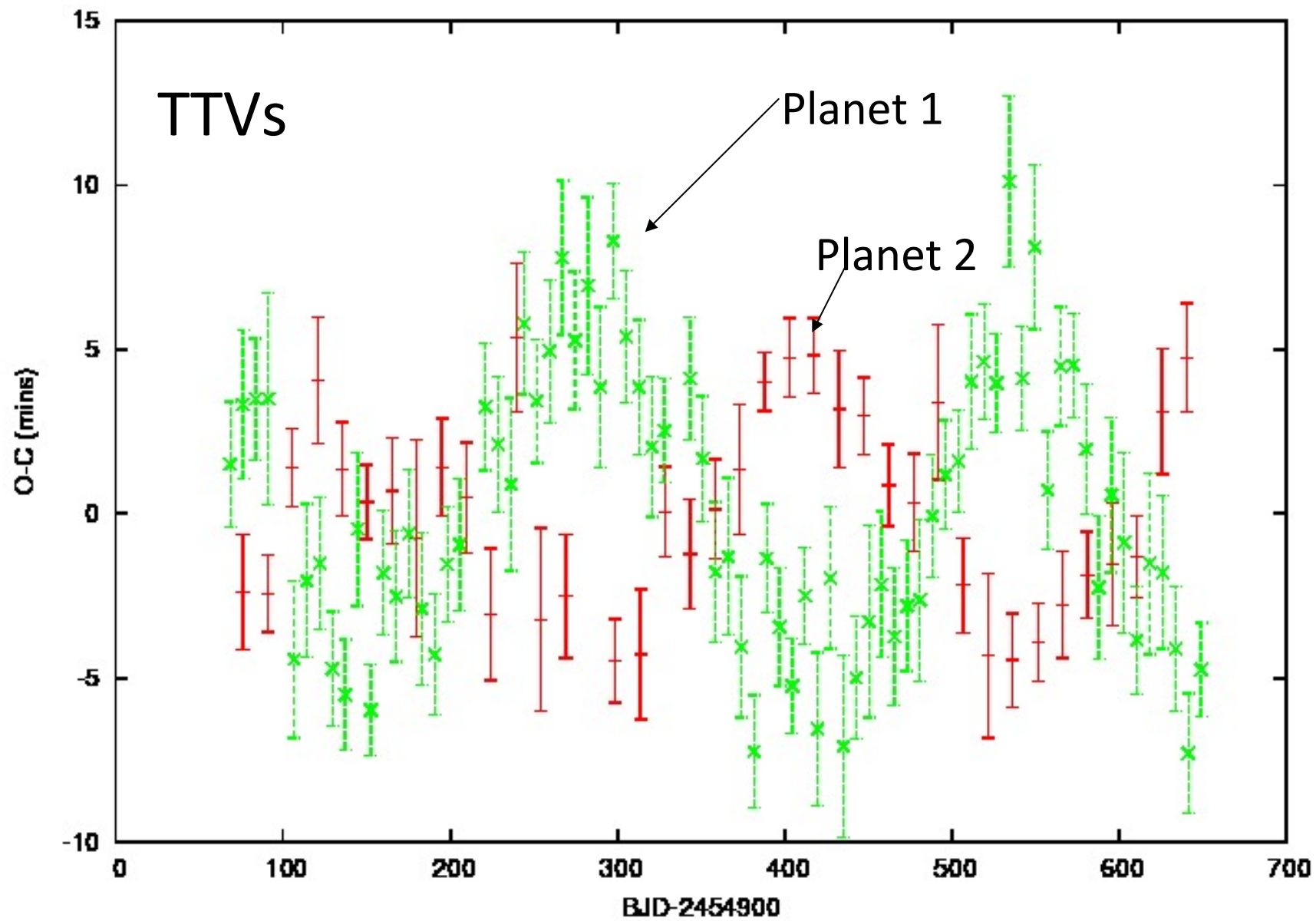


3 planet system

- 7.6, 14.9, 3.5 days
- 6.0, 8.6, 2.3 R_{Earth}
- RV and TTV detection of larger planets.
- Possible RV detection of inner planet

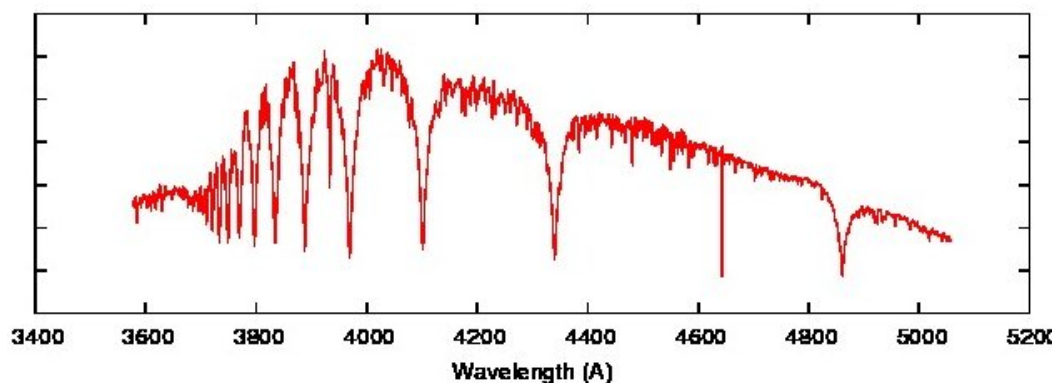




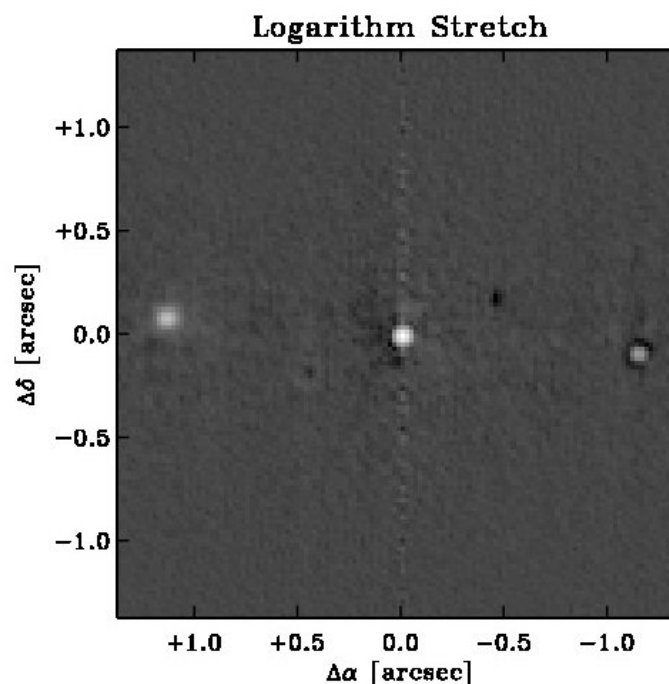


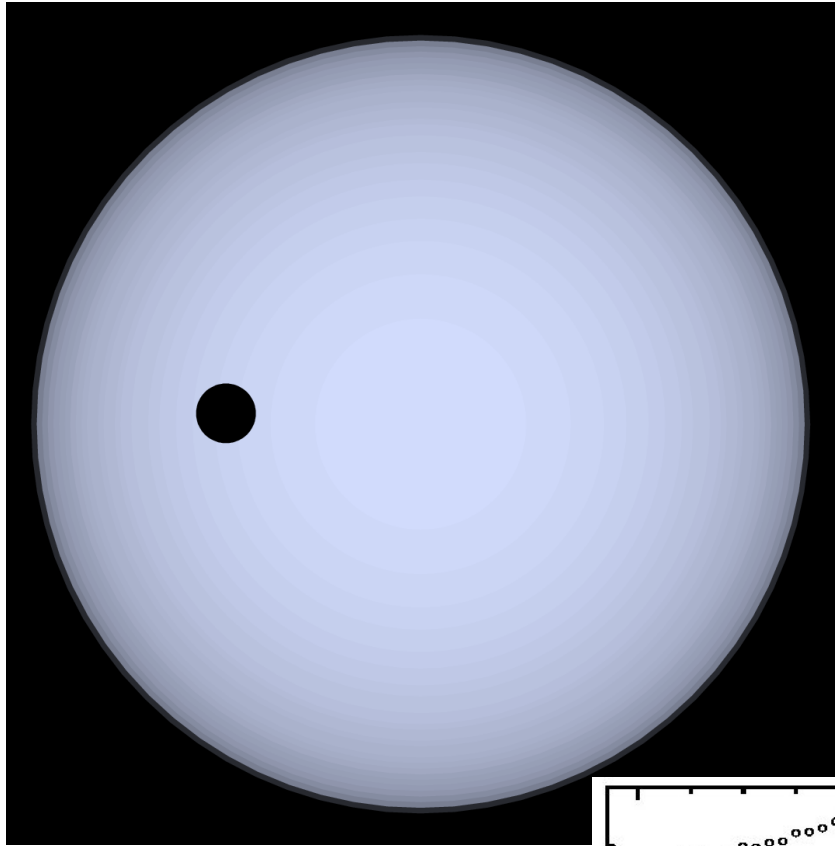
Spectroscopy & Speckle Follow-up

- Spectra 4-m Kitt Peak
 - A-star ~ 8850 K
 - Broad Balmer series
 - Not suitable for high-precision RV



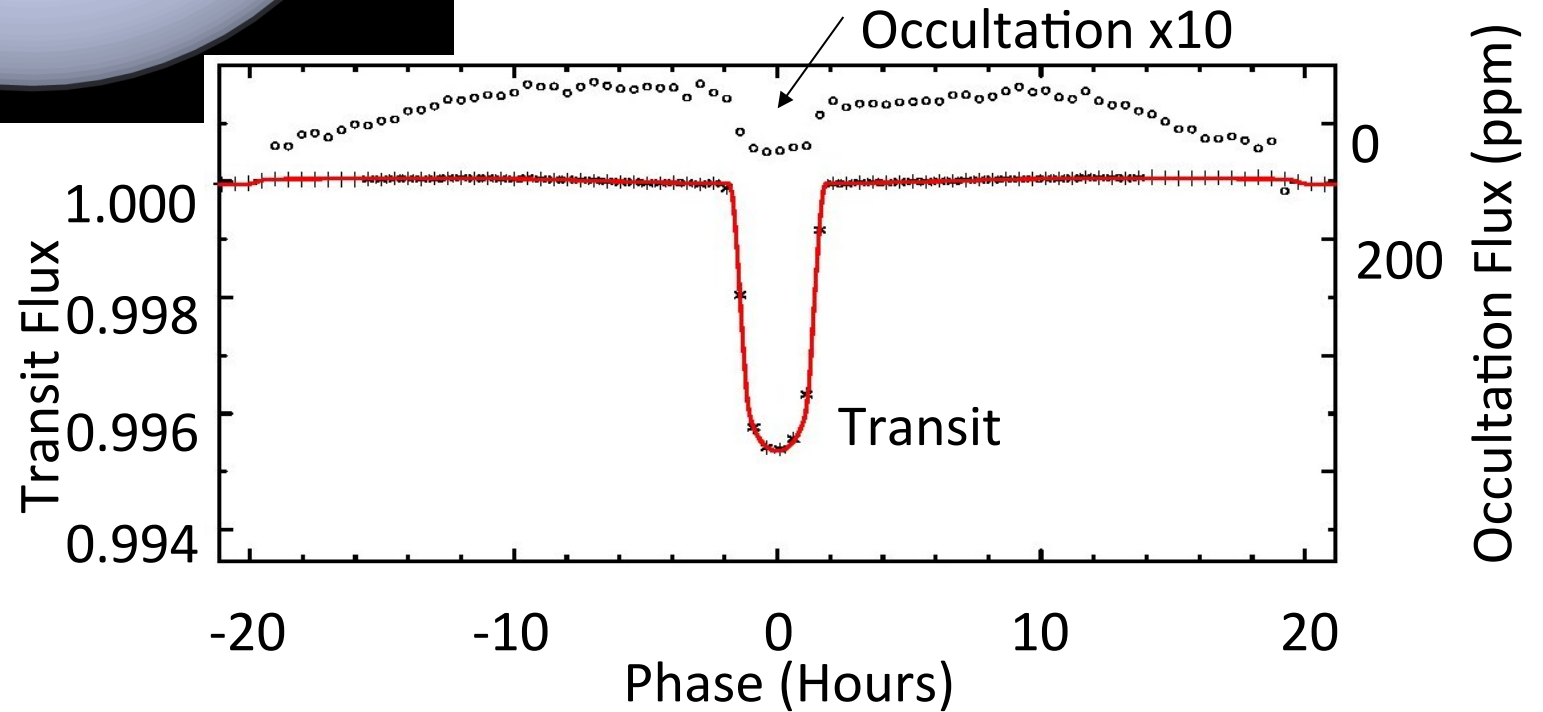
- WIYN Speckle
 - 2nd star detected
 - 1.2'' separation
 - Kepler: 4''/pixel
 - Dilution is
 - 32%
 - Transit is deeper than observed
- Spitzer confirmed

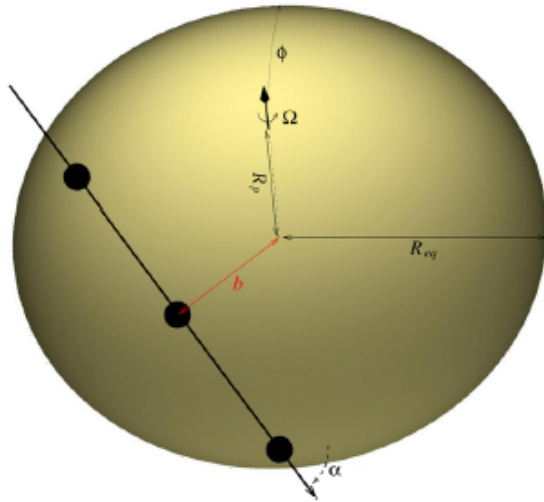




1 planet

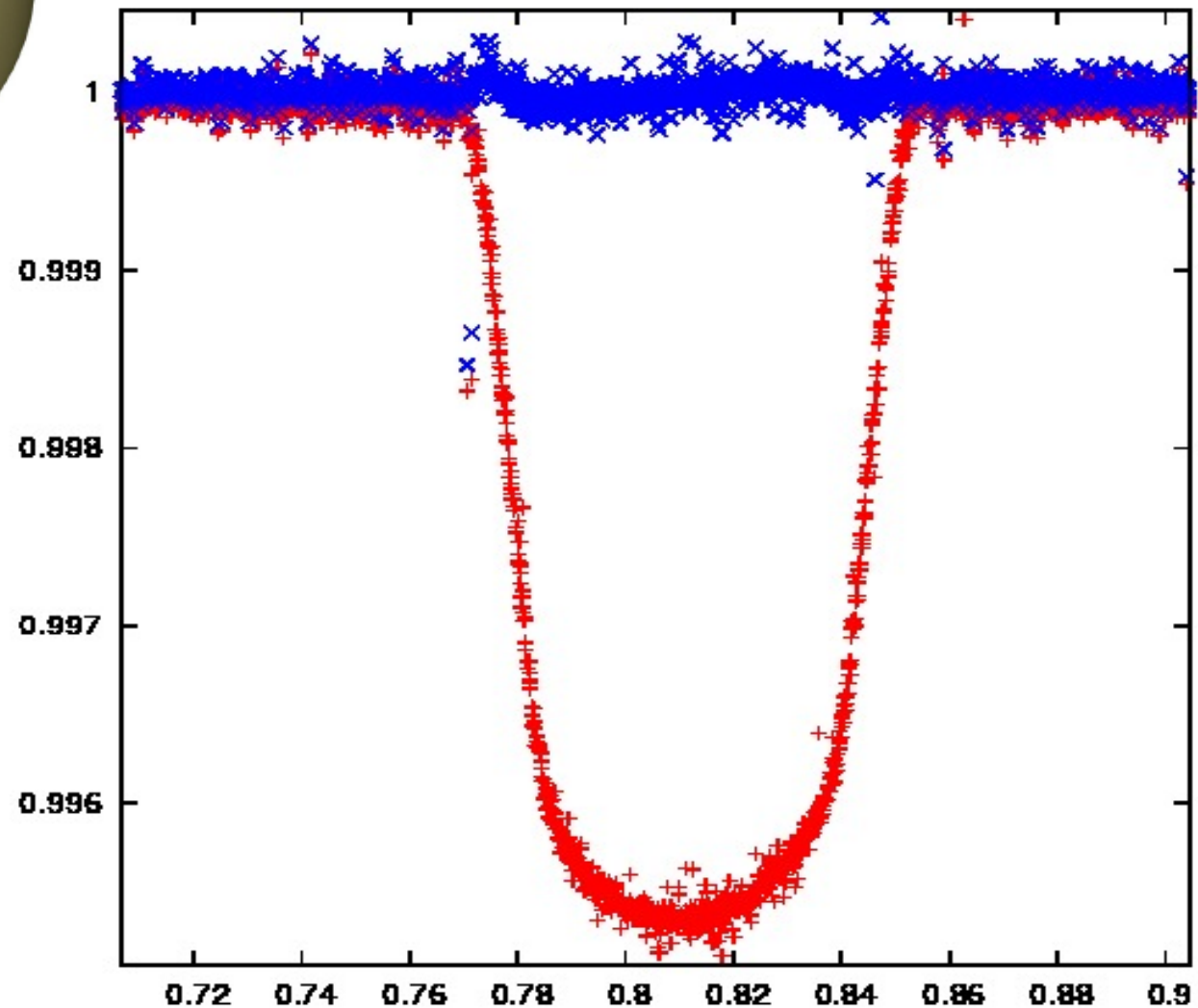
- Period = 1.8 days
- 1.2 R_{jupiter}
- 3.5 M_{jupiter}
- Phase, ellipsoidal and Doppler variability
- $T_{\text{eff}} = 3625 \text{ K}$ (6500 F)

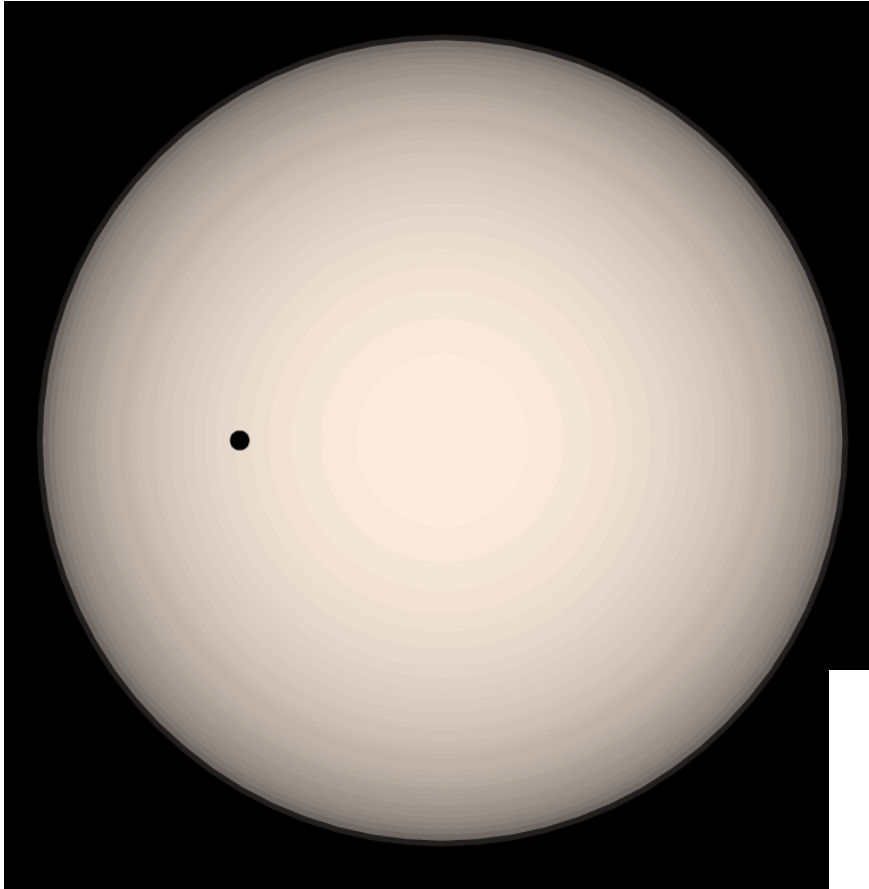




Stellar Rotation (van Zeipel effect)

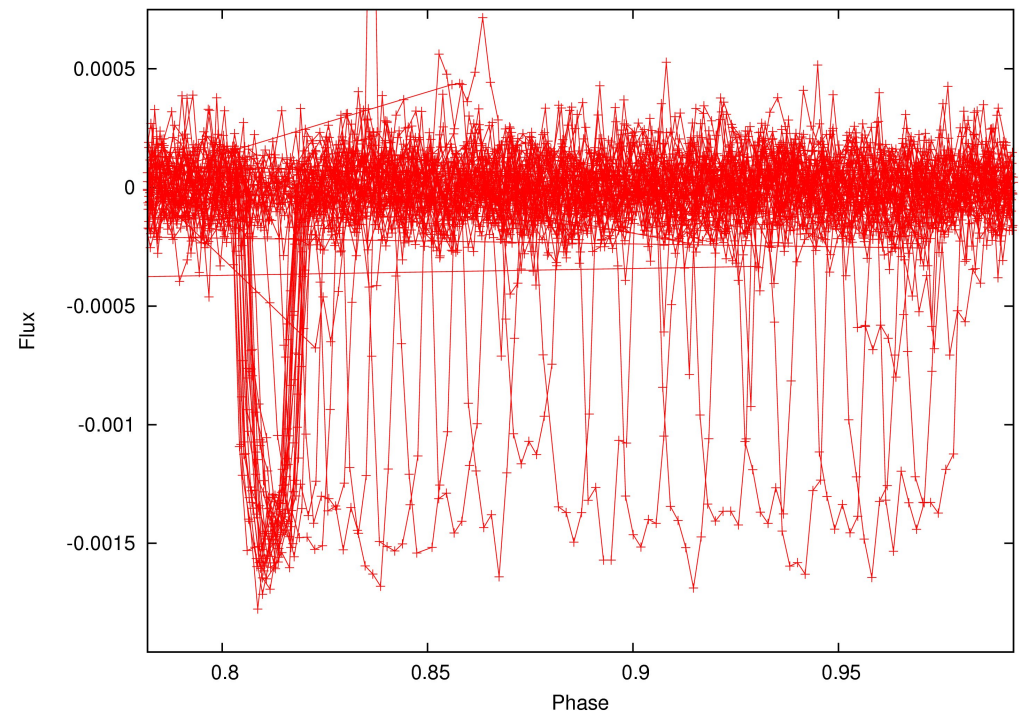
- $V \sin i \sim 100$ km/s
- Distorts star
- Limb-darkening is not symmetric
- Gravity darkening

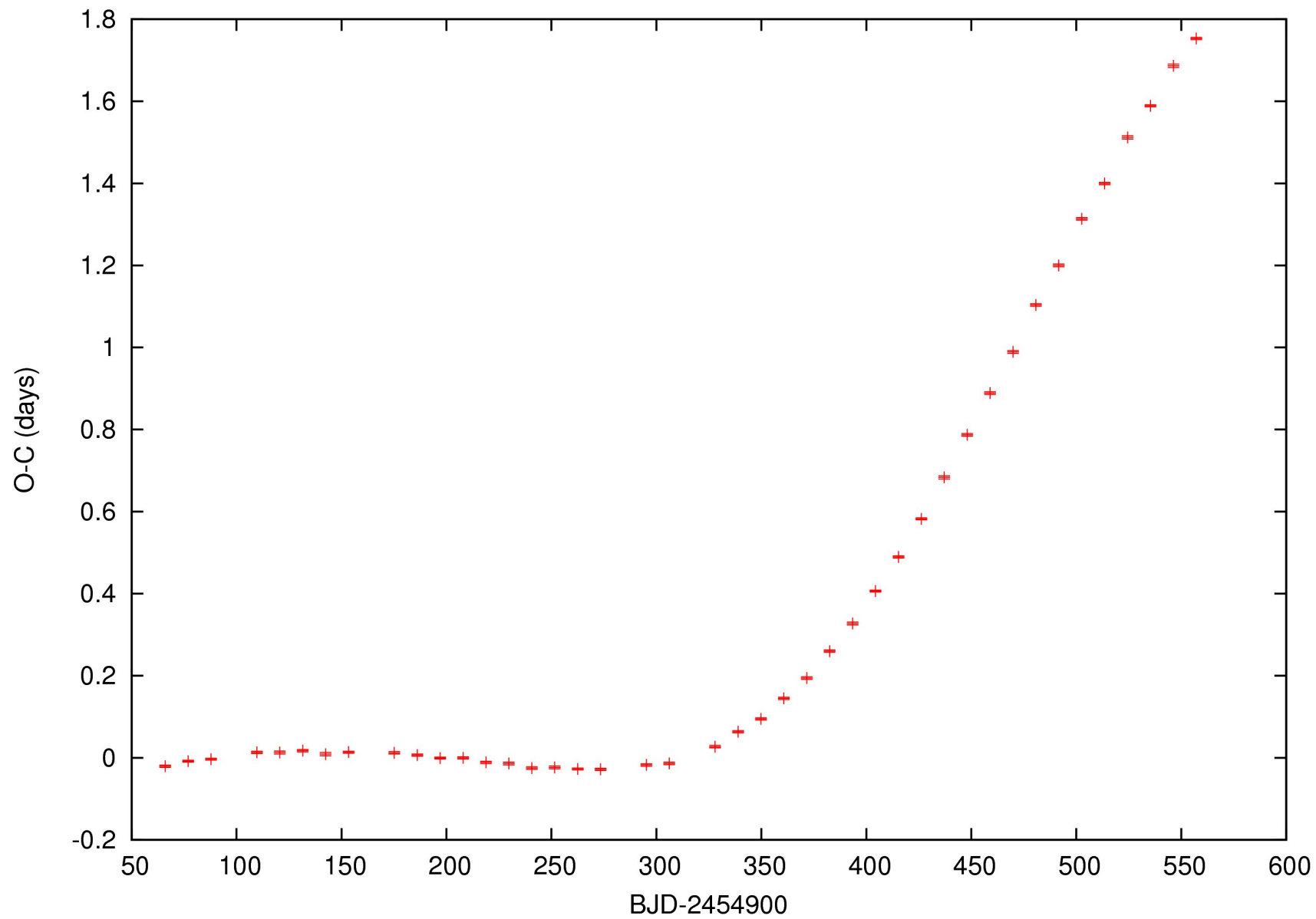


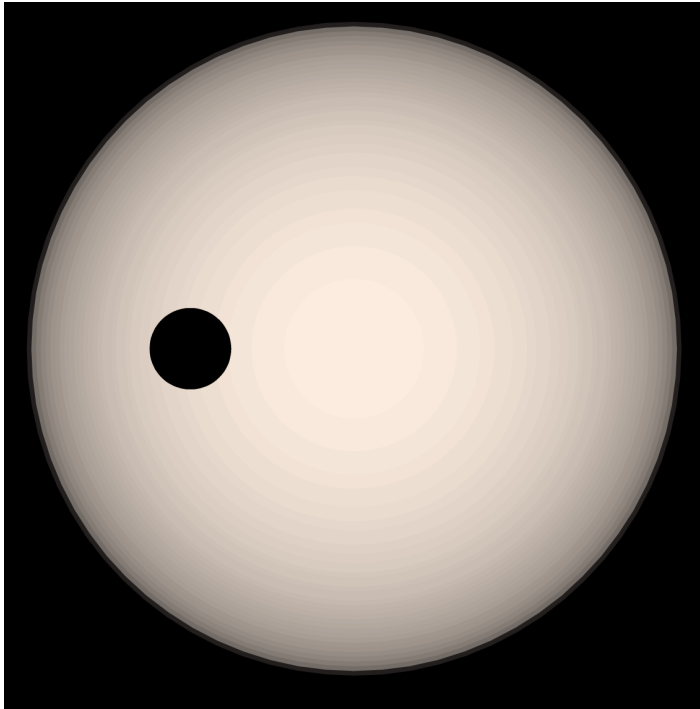


Large TTVs

- 1 planets
- 10.9 days
- 2.5 Rearth
- Larger TTV
- Another planet/star?

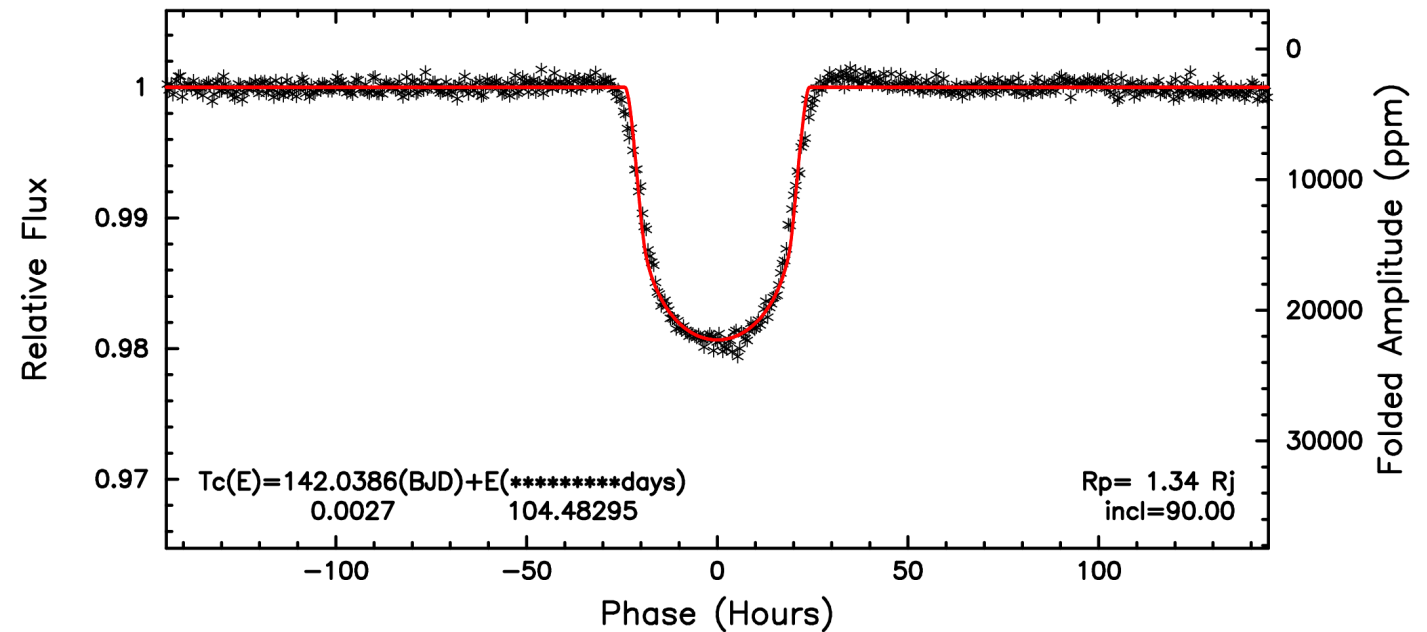




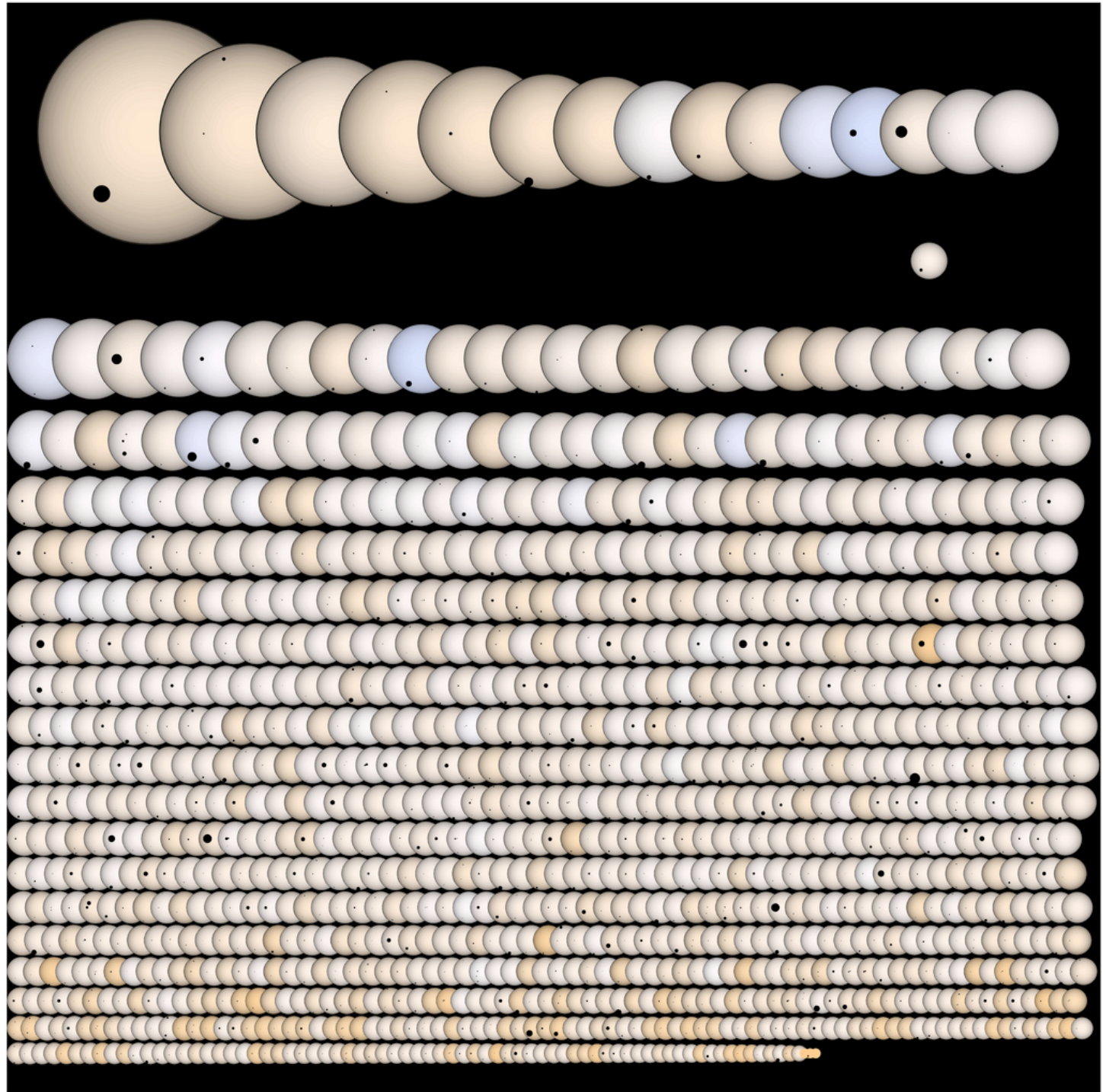


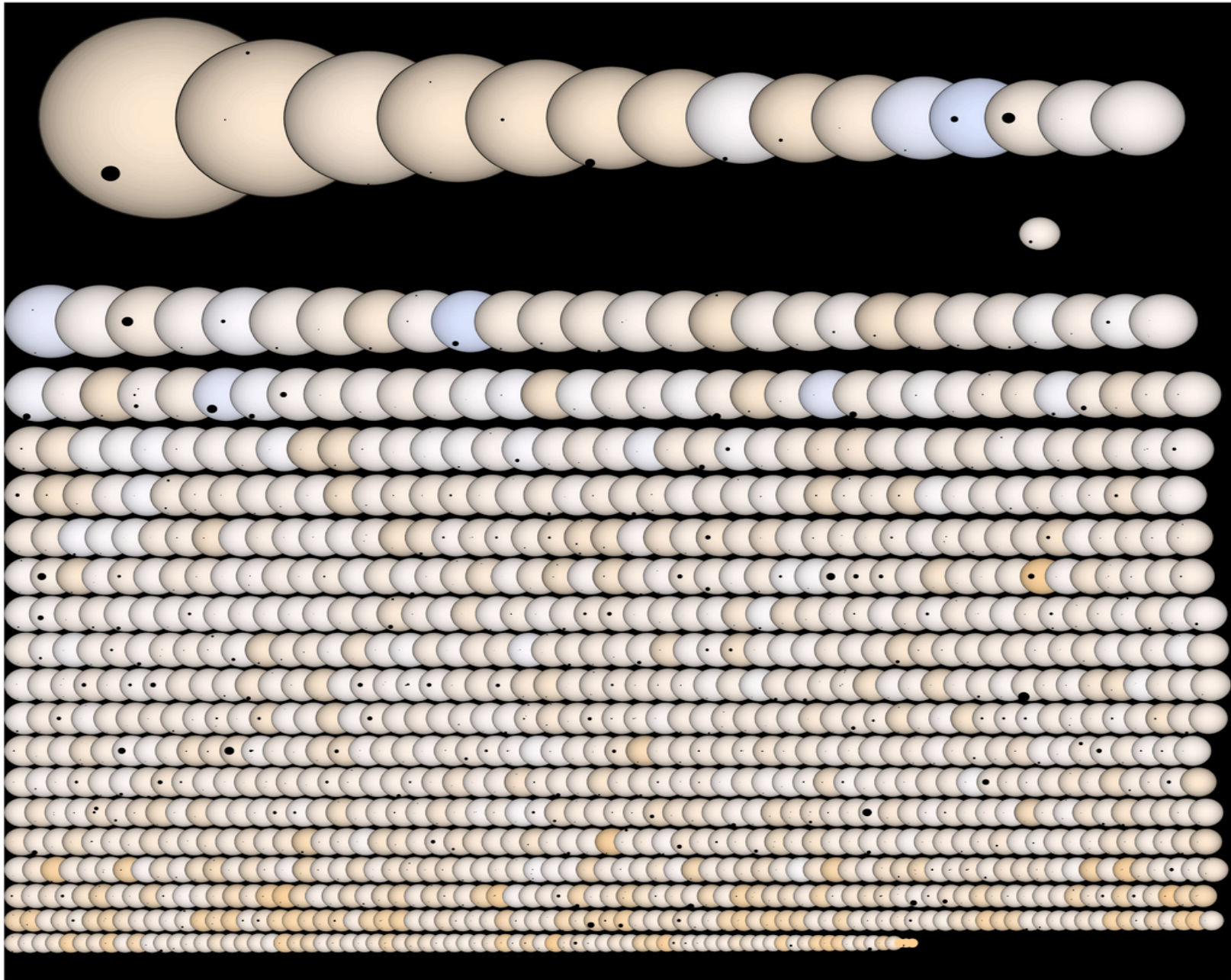
Long Period

- 1 planet
- 10000 days (30 years)
- 1.3 R_J
- 48 hour transit!
- Outer solar system



- All current KOIs
- 1820 KOIs
- Size to scale
- Colours match eye response
- Actual limb-darkening
- Modeled impact parameter





- Image by Jason Rowe, See: <http://www.flickr.com/photos/astroguy/5548755082/>

END

Kepler's Large, Close-In Planets

